Air Quality and Intelligent Transportation Systems: Understanding Integrated Innovation, Deployment and Adaptation of Public Technologies

by

Rebecca Susanne Dodder

B.A. Physics and Spanish – Vanderbilt University, 1997
M.A. Science, Technology and Public Policy – George Washington University, 1999

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Author

Engineering Systems Division

August 2, 2006

Certified by

Joseph M. Sussman, PhD
Professor of Civil and Environmental Engineering and Engineering Systems
JR East Professor
Thesis Supervisor

Certified by

Kenneth A. Oye, PhD
Associate Professor of Political Science and Engineering Systems
Thesis Committee Member

Certified by

Mario J. Molina, PhD
Institute Professor Emeritus
Professor Emeritus of Chemistry and Atmospheric Chemistry, and Environmental Studies
Professor of Chemistry and Biochemistry at the University of California, San Diego
Thesis Committee Member

Accepted by

Richard de Neufville, PhD
Professor of Engineering Systems
Chair, Engineering Systems Division Education Committee
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ABSTRACT

During the past two decades, Intelligent Transportation Systems (ITS) have provided transportation organizations with increasingly advanced tools both to operate and manage systems in real-time. At the same time, federal legislation has been tightening the linkages between state and local transportation investments and metropolitan air quality goals. In this context, ITS seems to represent a case of the potential synergies—or so-called “win-win” outcomes—that could be realized for the dual policy goals of air quality and mobility. If the various public sector organizations responsible for air quality and transportation could cooperate in deploying, assessing and further adapting these new technologies to take advantage of these synergies, they could achieve a “sustainable use” of ITS. However, looking beyond ITS and air quality, these issues point to broader questions of how to appropriately manage technology and its impacts on society, specifically those technologies deployed by the public sector. In particular, how does the public sector innovate and deploy technologies in ways that maximize the benefits, and minimize or avoid the negative impacts? In order to examine this phenomenon, this thesis takes the example of ITS and air quality to develop and test a broader framework of Integrated Innovation, Deployment and Adaptation of Public Technologies (IIDAPT).

In this thesis, we define and articulate a framework for IIDAPT, and identify testable conditions that make IIDAPT either more or less likely to occur. We identify seven conditions—based in the literature of political science, organizational theory, and public administration—that should, in theory, influence the ability of public agencies to achieve synergies for multiple policy goals through technology deployment. Having developed a theoretical framework for the conditions that influence IIDAPT, we then test those conditions using five U.S. cities—Los Angeles, Houston, Boston, Orlando, and Tulsa—as case studies in ITS and air quality. We then extend the framework to a non-US case, Mexico City, in order to further test the IIDAPT framework and to identify possible changes at the federal and local level to better align ITS deployments with both mobility and air quality goals in Mexico City.

This research explains some interesting outcomes in terms of failures by public sector agencies to take advantage of new, lower cost ITS technologies that can provide multiple benefits for both mobility and air quality. We find that “cheap” solutions, such as ITS rather than conventional infrastructure, are not always in an agency’s interests, as defined by the agency. Specifically, we found that lower-cost innovations may compete with an agency’s or elected official’s priorities for certain categories of investment, by undermining the ability to build up the case for that investment. The overarching conclusion, is that the possibilities for synergies (or “win-win” outcomes) must be defined, not according
to the stated policy objectives or mission of the public sector agencies, but according to the underlying interests and agendas of agencies, which may, or may not align with the public interest.

We also found that new information on the impacts of new ITS technologies on air quality does not generally lead to adaptation in the application of those technologies either to reduce negative impacts or to provide additional benefits for air quality. Even where evaluations of air quality impacts were required, those assessments were not well integrated into the process of technology deployment and later adaptation in the use of those technologies. Indeed, new information that can change the perception of possible mutual benefits is not always welcomed by agencies, and assessment methodologies will tend to reflect existing agency preferences.

However, there were reasons for optimism. We found that in response to an increasingly “severe” air quality problem (as defined by federal regulations), local agencies are in fact experimenting with the use of ITS to achieve air quality benefits as well as mobility benefits. Furthermore, by creating the Congestion Mitigation and Air Quality (CMAQ) program, a dedicated federal funding source for non-traditional transportation investments (such as ITS) with air quality benefits, agencies were provided with the resources and additional motivation to seek out and deploy ITS technologies with air quality benefits.

To conclude this work, we highlight possible areas of future theory development for IIDAPT, and point to additional technology and policy domains where the IIDAPT framework can be applied and tested.

*Thesis Supervisor: Professor Joseph M. Sussman*
*Title: JR East Professor of Civil and Environmental Engineering and Engineering Systems*
This thesis is dedicated to Aldo.

For your love and your faith in me and in us.
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ACRONYMS

ACC: Adaptive Cruise Control
APC: Automatic Passenger Counter
APTS: Advanced Public Transportation System
AQI: Air Quality Index
AQMP: Air Quality Management Plan
ARTS: Advanced Rural Transportation Systems
ATIS: Advanced Traveler Information System
ATMS: Advanced Transportation Management System
ATSAC/ATSC: Automated Traffic Surveillance and Control/Adaptive Traffic Signal Control (Los Angeles)
AVCS: Advanced Vehicle Control System
AVI: Automated Vehicle Identification
AVL: Automated Vehicle Location
AVR: Average Vehicle Ridership
BRT: Bus Rapid Transit
BTD: Boston Transportation Department
CA/T: Central Artery/Tunnel Project (a.k.a. the “Big Dig”)
CAAAA: Clean Air Act Amendments
CAD: Computer-Aided Dispatch
Caltrans: California Department of Transportation
CAM: Metropolitan Environmental Commission
CARB: California Air Resources Board
CBO: Congressional Budget Office
CCTV: Closed Circuit Television
CHP: California Highway Patrol
CLF: Conservation Law Foundation
CMAQ: Congestion Mitigation and Air Quality Improvement Program
CMEM: Comprehensive Modal Emissions Model
CMS: Changeable Message Signs (see also VMS and DMS)
CO: Carbon monoxide
Cometravi: Metropolitan Commission for Transportation and Roadways
CTA: Constructive Technology Assessment
CTMS: Computerized Transportation Management System
CTPS: Central Transportation Planning Staff (Boston area)
CVO: Commercial Vehicle Operations
DF: Federal District (Distrito Federal)
DMS: Dynamic Message Signs (see also VMS and CMS)
DOE: Department of Energy
E&E ITS: Emissions and Energy ITS
EAC: Early Action Compact
ECO: Employee Commute Options
EIA: Environmental Impact Assessment
EM: State of Mexico (Estado de Mexico)
EMFAC: California motor vehicle emissions factor model
EOT: Executive Office of Transportation (Massachusetts)
<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
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<tbody>
<tr>
<td>EPA</td>
<td>Environmental Protection Agency</td>
</tr>
<tr>
<td>ETC</td>
<td>Electronic Toll Collection</td>
</tr>
<tr>
<td>ETR</td>
<td>Employee Trip Reduction</td>
</tr>
<tr>
<td>EVSC</td>
<td>External Vehicle Speed Control</td>
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<tr>
<td>FAR</td>
<td>Flexible Attainment Region</td>
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<tr>
<td>FDOT</td>
<td>Florida Department of Transportation</td>
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<tr>
<td>FHWA</td>
<td>Federal Highway Administration</td>
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<tr>
<td>FTA</td>
<td>Federal Transit Administration</td>
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<tr>
<td>GAO</td>
<td>Government Accountability Office (General Accounting Office, before 2004)</td>
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<tr>
<td>GIS</td>
<td>Geographic Information System</td>
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<tr>
<td>GPS</td>
<td>Global Positioning System</td>
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<tr>
<td>HAR</td>
<td>Highway Advisory Radio</td>
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<tr>
<td>HC</td>
<td>Hydrocarbons</td>
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<tr>
<td>H-GAC</td>
<td>Houston-Galveston Area Council</td>
</tr>
<tr>
<td>HNC</td>
<td>Day without a Car (Hoy No Circula)</td>
</tr>
<tr>
<td>HOT</td>
<td>HOV/Toll</td>
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<tr>
<td>HOV</td>
<td>High occupancy vehicle</td>
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<td>HPMS</td>
<td>Highway Performance Monitoring System</td>
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<tr>
<td>I/M</td>
<td>Inspection and Maintenance</td>
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<tr>
<td>IbTS</td>
<td>Information-based Transportation Strategies</td>
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<tr>
<td>ICT</td>
<td>Information and Communications Technologies</td>
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<tr>
<td>IIDAPT</td>
<td>Integration Innovation, Deployment and Adaptation of Public Technologies</td>
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<tr>
<td>IMEA</td>
<td>Air quality index in Mexico</td>
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<td>IMT</td>
<td>Mexican Institute of Transportation</td>
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<tr>
<td>INCOG</td>
<td>Indian Nations Council of Governments</td>
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<tr>
<td>INE</td>
<td>National Institute of Ecology</td>
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<td>ISTEA</td>
<td>Intermodal Surface Transportation Efficiency Act</td>
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<td>ITS</td>
<td>Intelligent Transportation Systems</td>
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<td>IV</td>
<td>Intelligent Vehicles</td>
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<td>IVHS</td>
<td>Intelligent Vehicle-Highway Systems</td>
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<td>IVOMS</td>
<td>Integrated Vehicle Operation Management System (Houston)</td>
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<tr>
<td>JPO</td>
<td>Joint Program Office</td>
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<tr>
<td>KPH</td>
<td>Kilometers per hour</td>
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<td>LEV</td>
<td>Low Emission Vehicle</td>
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<td>LEZ</td>
<td>Low Emission Zone</td>
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<td>LPR</td>
<td>License Plate Recognition</td>
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<td>MADEP</td>
<td>Massachusetts Department of Environmental Protection</td>
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<td>MBTA</td>
<td>Massachusetts Bay Transportation Authority</td>
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<tr>
<td>MCMCA</td>
<td>Mexico City Metropolitan Area</td>
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<td>MIS</td>
<td>Major Investment Study</td>
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<td>MOBILE</td>
<td>EPA’s motor vehicle emissions model</td>
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<td>MOE</td>
<td>Measures of Effectiveness</td>
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<tr>
<td>MPH</td>
<td>Miles per hour</td>
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<td>MPO</td>
<td>Metropolitan Planning Organization</td>
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<td>NAAQS</td>
<td>National Ambient Air Quality Standards</td>
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<td>NCHRP</td>
<td>National Cooperative Highway Research Program</td>
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<tr>
<td>Abbreviation</td>
<td>Full Form</td>
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<tr>
<td>NEPA</td>
<td>National Environmental Policy Act</td>
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<td>NESCAUM</td>
<td>Northeast States for Coordinated Air Use Management</td>
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<tr>
<td>NGO</td>
<td>Non-governmental Organization</td>
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<tr>
<td>NHS</td>
<td>National Highway System</td>
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<tr>
<td>NMHC</td>
<td>Non-methane Hydrocarbons</td>
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<tr>
<td>NMT</td>
<td>Non-motorized Travel</td>
</tr>
<tr>
<td>NO</td>
<td>Nitrogen oxide</td>
</tr>
<tr>
<td>NO$_2$</td>
<td>Nitrogen dioxide</td>
</tr>
<tr>
<td>NO$_X$</td>
<td>Nitrogen oxides (includes both NO and NO$_2$)</td>
</tr>
<tr>
<td>NPRM</td>
<td>Notice of proposed rulemaking</td>
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<tr>
<td>O$_3$</td>
<td>Ozone</td>
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<tr>
<td>OBD</td>
<td>On-board Diagnostic</td>
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<tr>
<td>OCTA</td>
<td>Orange County Transportation Authority</td>
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<td>ODEQ</td>
<td>Oklahoma Department of Environmental Quality</td>
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<tr>
<td>ODOT</td>
<td>Oklahoma Department of Transportation</td>
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<tr>
<td>OOCEA</td>
<td>Orlando-Orange County Expressway Authority</td>
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<tr>
<td>OTAG</td>
<td>Ozone Transport Assessment Group</td>
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<tr>
<td>PATH</td>
<td>California Partners for Advanced Transit and Highways</td>
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<tr>
<td>PDA</td>
<td>Personal Digital Assistant</td>
</tr>
<tr>
<td>PITV</td>
<td>Mexico City's Integrated Program for Transportation and Roadways</td>
</tr>
<tr>
<td>PM$_{10}$</td>
<td>Coarse Particulate Matter (smaller than or equal to 2.5 micrometers)</td>
</tr>
<tr>
<td>PM$_{2.5}$</td>
<td>Fine Particulate Matter (smaller than or equal to 2.5 micrometers)</td>
</tr>
<tr>
<td>PMT</td>
<td>Person miles traveled</td>
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<tr>
<td>Proaire</td>
<td>Mexico City's Air Quality Program</td>
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<tr>
<td>RCTSS</td>
<td>Regional Computerized Traffic Signal System (Houston)</td>
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<tr>
<td>ROP</td>
<td>Rate of Progress</td>
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<tr>
<td>RPA</td>
<td>Roadside Pollution Assessment</td>
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<td>RTIP</td>
<td>Regional Transportation Improvement Program</td>
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<tr>
<td>RTP</td>
<td>Regional Transportation Plan</td>
</tr>
<tr>
<td>RVP</td>
<td>Reid Vapor Pressure</td>
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<tr>
<td>SCAG</td>
<td>Southern California Association of Governments</td>
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<tr>
<td>SCAQMD</td>
<td>South Coast Air Quality Management District (California)</td>
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<tr>
<td>SCT</td>
<td>Secretariat of Communication and Transportation</td>
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<tr>
<td>Semarnat</td>
<td>Secretariat of the Environment and National Resources</td>
</tr>
<tr>
<td>Setravi</td>
<td>Secretariat of Transportation and Roadways in the Federal District</td>
</tr>
<tr>
<td>SIP</td>
<td>State Implementation Plan</td>
</tr>
<tr>
<td>SMA</td>
<td>Secretariat of the Environment in the Federal District</td>
</tr>
<tr>
<td>SOS</td>
<td>Secretariat of Public Works and Services in the Federal District</td>
</tr>
<tr>
<td>SOV</td>
<td>Single Occupancy Vehicle</td>
</tr>
<tr>
<td>SSP</td>
<td>Secretariat of Public Security in the Federal District</td>
</tr>
<tr>
<td>STIP</td>
<td>State Transportation Improvement Program</td>
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<td>STP</td>
<td>Surface Transportation Program</td>
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<tr>
<td>STPP</td>
<td>Surface Transportation Policy Program</td>
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<tr>
<td>TCEQ</td>
<td>Texas Commission on Environmental Quality</td>
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<tr>
<td>TCM</td>
<td>Transportation Control Measure</td>
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<tr>
<td>TDM</td>
<td>Transportation Demand Management</td>
</tr>
<tr>
<td>TIP</td>
<td>Transportation Improvement Program</td>
</tr>
<tr>
<td>TMC</td>
<td>Transportation (or Traffic) Management Center</td>
</tr>
<tr>
<td>Acronym</td>
<td>Description</td>
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<tr>
<td>TNRCC</td>
<td>Texas Natural Resources Conservation Commission</td>
</tr>
<tr>
<td>TRB</td>
<td>Transportation Research Board</td>
</tr>
<tr>
<td>TSM</td>
<td>Transportation System Management</td>
</tr>
<tr>
<td>TSP</td>
<td>Traffic Signal Priority</td>
</tr>
<tr>
<td>TTI</td>
<td>Travel Time Index or Texas Transportation Institute</td>
</tr>
<tr>
<td>TxDOT</td>
<td>Texas Department of Transportation</td>
</tr>
<tr>
<td>UAM</td>
<td>Urban Airshed Model</td>
</tr>
<tr>
<td>US DOT</td>
<td>US Department of Transportation</td>
</tr>
<tr>
<td>US EPA</td>
<td>US Environmental Protection Agency</td>
</tr>
<tr>
<td>VMS</td>
<td>Variable Message Signs (see also DMS and CMS)</td>
</tr>
<tr>
<td>VMT</td>
<td>Vehicle Miles Traveled</td>
</tr>
<tr>
<td>VOC</td>
<td>Volatile organic compounds</td>
</tr>
<tr>
<td>WAPM</td>
<td>Wide-Area Pollution Monitoring</td>
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</table>
CHAPTER 1. BACKGROUND, MOTIVATION AND APPROACH
The social trend that is coming to have the greatest influence on transportation is the growing role of information processing and telecommunications in modern society.

- (Wachs 2002)

The enabling technology of ITS, the transportation/information infrastructure, can and will have profound effects.
We hope they will be positive—accessibility, economic growth, improved quality of life, improving information for planning and intermodal transport.
However, unforeseen outcomes, both positive and negative, are certain with this new transportation enterprise.

- (Sussman 2005)

It is sometimes said that we get the politicians we deserve. But if this is true, then we also get the technologies we deserve.
Our technologies mirror our societies.
They reproduce and embody the complex interplay of professional, technical, economic, and political factors....
Technologies, we are saying, are shaped.
They are shaped by a range of heterogeneous factors. And, it also follows, they might have been otherwise.

- (Bijker and Law 1992)
Intelligent Transportation Systems (ITS) represent the application of information and communications technologies (ICT) to the infrastructure and vehicles and that comprise the surface transportation system. For this thesis, we will be focusing primarily on ITS technologies that are applied to traditional urban transportation infrastructure (rather than vehicles) – highways (general purposes lanes and high-occupancy vehicle lanes), arterials and local streets, and public transportation. These include, but are not limited to, technologies for traffic signal network control, transportation operations/management centers, incident management systems, electronic toll collection, automated fare collection, and computer-aided dispatching of transit vehicles. Because we will be considering passenger travel (and not freight transportation), we will also analyze technologies that affect travel demand and trip-making patterns, such as traffic and transit traveler information, transit trip-planning services, congestion pricing, and ridesharing services. In-vehicle technologies, such as collision prevention systems and vehicle navigation, may also have important environmental impacts, and we briefly discuss the possible air quality implications of some of these “intelligent vehicle” technologies. Yet, for the purposes of this thesis, we are more interested in “intelligent infrastructure” technologies. In general, these technologies are deployed by public sector agencies – city and county public works or transportation departments, state departments of transportation, transit agencies, and others. Some observers also look to information and communications technologies as substitutes for transportation, substituting flows of information for flows of travelers and goods. However, we will be looking at how information is used to manage travel, not substitute for travel.

As noted by Sussman and Wachs, ITS and ICT have the potential to transform transportation systems. Yet, while substantial progress has been made by the public sector in deploying ITS across urban transportation systems, we consider ITS to still be in its so-called formative years. For example, as of 2004, only 35% of US freeway miles had real-time traffic data collection technologies, one of the basic ITS components for nearly any type of freeway management strategy. Less than half of vehicles in transit fleets in the US had automated vehicle location, a critical component for most transit ITS applications. It is likely that an even lesser percentage of vehicle fleets and freeway and arterial miles are actually managed in real time using these technologies. Therefore, the question is, what will transportation systems look like in the future? How will ITS, when more fully deployed, affect our transportation systems, our cities, and our mobility? How will ITS affect our urban environments, for example, land use, habitat integrity, noise, water quality and air quality? Speculation on this topic has led to the articulation of very different visions by transportation experts. Cervero takes the following view of ITS:

1 To summarize, looking ahead to Chapter 2, we will focus on Advanced Transportation Management Systems, Advanced Public Transportation Systems, and Advanced Traveler Information Systems (see Table 2-2).
2 According to a Government Accountability Office (GAO) report, the level of ITS deployment, even of currently available technologies, is below what was originally hoped for when the US National ITS Program was launched approximately 15 years ago (US GAO, 2005).
In a decade or two, travel by automobile in some advanced countries may very well involve the kind of technology and intelligence gathering once reserved for tactical warfare. Onboard navigational aids, fed by satellite tracking systems, will give directions in soothing digital voices. In big cities, roadside screens will flash messages about distant traffic jams and alternative routes. Computerized control and guidance devices embedded underneath heavily trafficked corridors will allow appropriately equipped cars and trucks to race along almost bumper to bumper. Although its goals of enhanced efficiency, comfort and safety are unimpeachable, its inevitable costs — spiraling fuel consumption, air pollution, suburban sprawl and urban decay — are sobering" (Cervero 1995, italics added).

As the title of his article — Why Go Anywhere? — suggests, Cervero prefers the concept of the substitution of travel by ICT and appropriately-designed communities, to the enhancement of currently predominant modes of travel. Other authors, like Jordan and Horan, take a more optimistic view of the potential for ITS to support sustainable communities:

“ITS offers the prospect of an information-intensive transportation system, in which the information provided could increase mobility, reduce environmental damage, and better serve the interests of communities” (Jordan and Horan 1997).

Similarly, Michael Replogle, with Environmental Defense, stressed that the use of ITS for demand management strategies could be:

“the most important enabling technology driver in decades to reform and progress in American transportation, winning for our citizens sustainable high wage jobs, reduced traffic delay, more livable communities, and a healthy environment” (Replogle 1994).

We find in these statements — all from the mid-1990s, when ITS technologies were starting to be more widely deployed and integrated — very different and plausible visions of what the impact of ITS could be, how ITS technologies could be deployed, and for what purposes they could be used. The fact that there is controversy among academics and professionals regarding the design and, perhaps more importantly, the use of ITS technologies, and how that will affect communities, makes this a fruitful area of investigation. It suggests that we will both find different outcomes from one area to another in terms of how those systems are being developed, and, we hope, identify the reasons for different outcomes or versions of those systems.

In this thesis, we will not attempt to predict the future of ITS and how it will influence the future of cities. We take a very modest, and perhaps more practical approach to looking at this issue of the “social shaping” of ITS and its impacts, looking at five metropolitan areas in the US and, for a non-US comparison, Mexico City. We will look not at the broader questions of sustainable transportation and sustainable development, but rather a more tightly bounded, but important component of sustainability, which is urban air quality. Therefore, framed by this concept of the social shaping of technologies, we will ask the question: Are ITS technologies being shaped to promote air quality objectives, and, if so, how?
1.1 BACKGROUND

During the past two decades, Intelligent Transportation Systems (ITS) have provided transportation organizations with increasingly advanced tools both to operate and manage systems in real-time and to plan future systems with much more detailed information regarding system performance. At the same time, federal legislation was tightening the linkages between state and local transportation investments and metropolitan air quality goals. Some observers from the transportation profession saw in ITS an opportunity to improve the efficiency of transportation systems, while at the same time better addressing air quality concerns. Traffic flow could be managed in ways that would mitigate congestion, thus reducing emissions from idling and stop-and-go traffic conditions, while public transit technologies could improve both the operation and image of its service to attract new ridership away from the predominant use of the single-occupancy automobile. Many in the environmental community were less enthusiastic about the potential environmental enhancements that could be created by ITS, given their concern with additional travel demand induced by enhanced capacity, but also saw some possibilities for furthering air quality goals, such as congestion pricing and support of Transportation Demand Management (TDM) strategies.

Fundamental changes to US metropolitan transportation and air quality planning were ushered in with the passage of the 1990 Clean Air Act Amendments (CAAA) and the 1991 Intermodal Surface Transportation Efficiency Act (ISTEA). While the CAAA created more stringent requirements for metropolitan transportation planners to show that their plans, programs and projects conformed to the purposes of the state air quality plans for meeting the National Ambient Air Quality Standards (NAAQS), ISTEA both recognized that transportation must serve other goals beyond safety and mobility, and provided a funding program for projects aimed at mitigating the air quality impacts of transportation systems (Shrouds 1993; Savonis 1995). At the same time, many important players in the transportation profession were beginning to rally around an emerging national program of Intelligent Vehicle-Highway Systems (IVHS), or Intelligent Transportation Systems (ITS). ITS is defined as “the application of computers, communications and sensor technology to surface transportation” (ITS America 2002). Federal government agencies, universities and research institutes, auto manufacturers, defense firms, communications product and services providers, and highway policy interest groups, were envisioning new solutions to many long-standing transportation problems. ISTEA was a watershed for the ITS community, creating the National ITS Program, with funding for ITS research and development, architecture and standards development, as well as funding to move emerging technologies to the real-world through field operational tests and other more deployment-oriented funding.

With the 1990 CAAA and 1991 ISTEA, Intelligent Transportation Systems and air quality would thus become linked in many ways. It was recognized that the strategy of building more roadway capacity as the default solution to worsening congestion in metropolitan areas was no longer a viable or desired option, due to environmental and social impacts and financial limitations on

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4 The term Intelligent Vehicle-Highway Systems (IVHS) was changed to Intelligent Transportation Systems (ITS) in late 1994.
highway expansion. This would set in motion a shift towards a more operations-oriented strategy, enabled in large part by the capabilities provided by ITS technologies to “manage” infrastructure using real-time information on the system’s performance, which could improve air quality through smoother traffic flows. Because of air quality and other environmental and social concerns, such as environmental justice, increasing emphasis was also given to boosting public transportation ridership. ITS technologies for public transportation could improve control over transit fleet operations, and provide a higher quality of service to the passenger, through technologies such real-time information and electronic fare payment.

However, these changes represent only the supply side of the equation. Although fuel and vehicle improvements were making substantial headway in reducing vehicular emissions and improving air quality, increases in vehicle miles traveled (VMT) were constantly threatening to diminish those gains (Shrouds 1993). Therefore, on the demand side, there was a reemphasis on many of the traditionally unpopular transportation demand management (TDM) strategies in an attempt to control the growth in VMT. However, these measures now could be facilitated, expanded, and made more palatable to the traveling public using ITS. For example, carpool and vanpool organization could increasingly be carried out via online services. The idea of dynamic congestion pricing, praised by economists as a more efficient way of allocating scarce highway capacity, but generally feared by politicians for their possibly negative political repercussions, now offered to be technically feasible, through electronic toll collection, and more acceptable to the public by integrating it with high-occupancy vehicle (HOV) lanes in the US. Finally, ITS applications could also provide new ways to improve traditional vehicle inspection and maintenance (I/M) programs to better control the emission levels from the vehicle fleet, in particular, by identifying problematic high emitters or exempting clean vehicles through remote sensing.

This points to a number of researchable questions regarding the role of ITS in transportation and environmental planning and management in the post-ISTEA and 1990 CAAA era. We will now present the approach that we selected, including the specific research questions we addressed, and the methodology used.
1.2 RESEARCH APPROACH

ITS seems to represent a case of potential synergies—so-called “win-win” outcomes—that could be realized for the dual policy goals of air quality and mobility through the adoption of new technologies. However, we also recognize that ITS technologies are deployed by the public sector primarily as a mobility strategy, typically for congestion mitigation purposes, but often for safety reasons as well. Therefore, environmental gains, such as air quality benefits, must “piggyback” on mobility gains. It follows, that if those public sector organizations responsible for air quality and those responsible for transportation could cooperate in innovating, deploying, assessing and further adapting these new technologies to take advantage of these synergies, in theory, they could use ITS in a way that would also improve air quality.

Therefore, what is needed is a framework for understanding how the public sector organizations that are deploying ITS, can innovate and adapt these new technologies in order to integrate air quality objectives. To point ahead, we will describe the phenomenon of interest as Integrated Innovation, Deployment and Adaptation of Public Technologies, or IIDAPT. We will explain this concept in greater depth in later sections. But first, we examine our research questions.

1.2.1 Research Questions

There are several important questions that will guide this thesis. We begin with what appears to be a straightforward question:

*How does ITS improve/degrade air quality?*

As we explore this issue in Chapters 2 and 3, we will find that there is no generalizable answer to this question. Indeed, we find that this is not the right question to be asking. Instead, we should be looking at how ITS technologies are deployed for air quality purposes and why, or why not. Therefore, we turn to the core research questions of this research:

*What conditions lead to higher/lower levels of IIDAPT in using ITS to support air quality goals in addition to mobility goals?*

*Can we develop and test/validate a theoretical framework for predicting what levels of IIDAPT will occur?*

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5 For example, historians and sociologists of science and technology who reject the idea of technological determinism, would argue that this sets up the question in a way that gives too much “agency” to the technological artifacts. They would argue that the technology itself does not have an inevitable internal trajectory, with inevitable social impacts. Instead, the technology and its impacts are applied and shaped by society. The question should be posed: how is ITS designed, applied, and used by society in ways that affect air quality, and is that effect generally negative or positive? For examples of this line of research, see Smith, M. R. and L. Marx, Eds. (1994). Does technology drive history?: the dilemma of technological determinism. Cambridge, MA, MIT Press. Also see Pinch, T. J. and W. E. Bijker (1987). The Social Construction of Facts and Artifacts: Or How the Sociology of Science and the Sociology of Technology Might Benefit Each Other. The Social Construction of Technological Systems. W. Bijker, T. Hughes and T. Pinch. Cambridge, MA, MIT Press: 17-50.
This highlights the theory building and theory testing component of this work. Looking beyond just ITS and air quality, these issues point to broader questions of how to appropriately manage technology and its impacts on society, particularly technologies deployed by the public sector. Specifically, how does the public sector innovate and deploy technologies in ways that maximize the benefits, and minimize or avoid the negative impacts? In this manner, we address the concept of the “social shaping” of technologies, to see how ITS technologies are being deployed, by whom, and whether air quality is generally being “traded-off” for improved mobility, or whether air quality and mobility are being “co-produced” through the deployment of ITS. Drawing upon our case studies of five US cities, and one non-US city, Mexico City, we will also answer the following question: are ITS technologies being “shaped” to promote air quality objectives, and if so, how?

We will also seek to use this framework in a more normative sense, in order to provide prescriptive advice regarding how to promote higher levels of IIAPT. This points us to the final research question of this thesis:

*Can we then use this framework to provide policy recommendations for fostering higher levels of IIDAPT, and thus generate greater benefits for multiple policy goals?*

We will now describe the methodology that we will follow to address these questions.

### 1.2.2 Methodology

The distinct visions of the impact of ITS on urban communities – as illustrated by the quotes by Cervero, Jordan and Horan, and Replogle presented above – suggest that the technologies themselves are not responsible for the air quality impacts of ITS. Indeed, the question of which of these visions will ultimately emerge, depends upon the ability and willingness of agencies to use ITS to support multiple goals, such as air quality in addition to mobility goals. Notwithstanding, there are important technical uncertainties regarding the way in which ITS can affect air quality. Therefore, we describe our methodology beginning with this first question of how ITS improves or degrades air quality.

#### 1.2.2.1 Assessment of Air Quality Impacts of ITS

We first address the issue of how ITS technologies can be beneficial or detrimental to air quality. Again, we argue that the air quality impacts of ITS are contingent upon how those technologies are applied and used by the organizations deploying and managing them. However, it is important to understand the scientific and technical uncertainties underlying many of the debates over ITS and its air quality impacts. It is also important to evaluate the “state-of-the-art” and “state-of-the-practice” in terms of modeling and measuring how ITS affects air quality, since this information is often employed by actors to make the case for or against ITS as an emission reduction measure.
While there has been a growing number of studies critically examining the air quality impacts of ITS, they are enough only to state that the jury is still out on the system-level and long-term impacts. Knowledge has improved substantially for some pieces of the ITS-air quality puzzle, such as how changes in acceleration and idling change emissions factors on a gram/mile basis. Other aspects, such as the potential for induced demand for travel, remain relatively unexplored. Therefore, we focus on the following issues:

- How does ITS improve/degrade air quality?
- Which ITS applications have been shown to have an important impact on air quality?
- Are there ITS applications specifically oriented toward the goal of improving air quality or reducing fuel use?
- When deploying multiple ITS services – often along with conventional infrastructure deployment – how can one unravel the overall air quality impacts?

We review the current literature related to the air quality impacts of ITS, in order to answer the first three questions. In response to the fourth question, in Chapter 3, we then present a qualitative systems framework for mapping out the possible air quality impacts from deploying multiple ITS applications. What we find is that one cannot generalize as to the benefits or negative impacts of ITS on air quality by looking only at the technologies themselves. Saying that ITS technologies are either “good” or “bad” for air quality, would oversimplify the problem. The impact that these technologies will have depends upon how these technologies are deployed and used in practice, and whether air quality goals are integrated into the decisions for deployment and application of these technologies.

1.2.2.2 Development of IIDAPT Framework

For this reason, we focus the core efforts of this thesis on identifying the conditions supporting and inhibiting the adoption and use ITS technologies in ways that attempt to maximize the air quality benefits, or reduce the negative air quality impacts of ITS. We develop a framework for multiple public sector organizations cooperating in the deployment, assessment and adaptation of new technologies. We more fully describe the desired outcome as the following:

*Public sector organizations cooperate to adopt and use new technologies in support of multiple policy goals. This process of innovation is iterative, as agencies assess impacts and adapt technologies to new information on outcomes.*

We refer to this as Integrated Innovation, Deployment and Adaptation of Public Technologies (IIDAPT). The term integrated suggests the active pursuit of multiple public policy goals that pertain to more than one public sector agency. This may be through active involvement and cooperation of several (at least two) agencies in the design and deployment of a new technology, or the more unilateral initiative of one agency to support the organizational and policy goals of other agencies (in addition to their own goals), during the process of innovation and deployment. Deployment indicates that we are focusing only on technologies that actually reach the operational stage, not technology development, research or invention (although those may be...
activities leading up to deployment). We use the term *innovation* with two ideas in mind. First, there is innovation in the application of advanced technologies (such as ICT) to new sectors (such as transportation). Second, there is another layer of innovation when these advanced technologies (ICT), are applied to a new sector (transportation), in support of non-traditional goals (air quality). Therefore, innovation, as we are using it here, is a combination of technological innovation, with the adoption and adaptation of advanced technologies, and policy innovation, in using these technologies in novel ways for reaching additional policy goals. We also use the term *adaptation* to refer to the process of continual assessment of technologies and their impacts, using the information that is generated during the evaluation process to improve and modify the already implemented innovation, and/or designs for future deployments. Finally, we use the term *public technologies* to indicate that these are technologies deployed primarily by public sector organizations (although there may be additional cooperation and support from other organizations), and that the technologies are intended to provide public benefits or public goods. In the case of this research, those public benefits are mobility and accessibility and air quality.

We further suggest that there is a scale of IIDAPT outcomes. High IIDAPT levels, for example, might reflect a more active involvement of various agencies and tighter integration of both mobility and air quality concerns. High IIDAPT would also reflect the use of more advanced technologies, or application of technologies in highly novel ways to support multiple policy goals. High quality evaluations and continuous adaptation of technologies to improve outcomes, would also be a characteristic of high IIDAPT. At the other end of the scale, low IIDAPT outcome would reflect minimal integration of air quality concerns into ITS deployments, sporadic assessment and little adaptation to new information, and the use of less advanced technologies. Our hypothesis is that levels of IIDAPT are influenced by certain conditions that promote or inhibit the adoption of new technologies in support of multiple policy goals.

- **IIDAPT Framework**

Having articulated the IIDAPT framework for managing complex socio-technical systems and their impacts, the next step is identifying some of the conditions supporting or inhibiting IIDAPT. For this, we turn to the literature on organizational theory, public administration, and political science. In Chapter 4, we synthesize the literature for three core areas relevant to IIDAPT: innovation in government, cooperation between organizations for achieving multiple policy objectives, and the role of assessment and adaptation of technologies. These theories are briefly introduced below. Figure 1-1 gives a preview of the IIDAPT framework, with the seven conditions leading to IIDAPT.
The review of the literature points us to four activities supporting high levels of IIDAPT: innovation, cooperation, assessment and adaptation. This figure shows the relationship between the seven conditions, and how they affect the four activities that support IIDAPT: cooperation, innovation, assessment and adaptation. We hypothesize that these conditions can have either a negative or positive influence on the levels of IIDAPT (as indicated by the “+” or “−”).

**Measurement of Conditions and Outcomes**

However, in order to develop a more rigorous framework, we have to be consistent in the measurement of both the conditions leading to IIDAPT and actual IIDAPT levels. As already mentioned, IIDAPT can be considered a scale, ranging from low to high IIDAPT. Although we do not quantify the conditions, we do create a scale to quantify actual levels of IIDAPT, which we will measure in the case studies. This consists of a numerical scale for the level of IIDAPT. This scale is based upon the levels of innovation, cooperation, assessment and adaptation, the activities identified in the literature as supporting high levels of IIDAPT.

While this scale is developed for application to individual technology deployments, we also develop a process for “scaling up” from individual technologies to the metropolitan level. The motivation for scaling up from individual technology deployments to the metropolitan area, is that we are interested in “aggregate” IIDAPT outcomes. We want to know how the seven conditions within a metropolitan area influence IIDAPT levels at a metropolitan level. In other words, can the seven conditions predict the levels of “innovativeness” of a metropolitan area in using ITS for air quality purposes?
1.2.2.3 Case Studies of ITS and Air Quality in the US

The hypothesis of this thesis is that there are conditions, which vary from city to city, that determine to the levels of IIDAPT that will occur for ITS and air quality. This follows directly from our core research questions presented in Section 1.2.1. A contribution of this thesis is to identify these conditions, and test them across a set of five in-depth case cities. We chose these five cities through a process of "purposive sampling," rather than taking a random sample of all medium to large US metropolitan areas (we chose from a total of 78 areas). We selected what would be considered two extreme cases, in terms of air quality problems as well as existing levels of ITS deployment, and three other cities that were intended to (and did) capture a range of IIDAPT outcomes. The five cities chosen were Los Angeles (California), Houston (Texas), Boston (Massachusetts), Orlando (Florida), and Tulsa (Oklahoma). It should be noted, that because the levels of IIDAPT for each city could only be assessed after the fieldwork was completed and the cases were analyzed, cases could not have been chosen purposefully to reflect a range of IIDAPT levels. Yet, we found that the cases also presented a good distribution of IIDAPT, from low to high.

The fieldwork for the case studies involved a series of interviews with analysts, planners, program managers and directors from public sector agencies at the city, county, and state level. Typically, face-to-face interviews, ranging from one to two hours, were carried out with individuals from the metropolitan planning organization, state environmental agency, state transportation agency, city and county transportation or public works departments, city or county transit agencies, and toll authorities. These interviews were carried out to assess the level of use of ITS for air quality, identify related studies, gain insights into the motivations and barriers toward using ITS for air quality goals, and raise specific questions related to the use of ITS for transportation control measures (TCMs) in air quality plans, and the use of the Congestion Mitigation and Air Quality (CMAQ) program for ITS deployments. In addition to the information from the interviews, the case histories (in Chapter 5) were developed based on transportation and air quality plans and programs, air quality conformity determinations, meeting minutes from metropolitan planning organization committee meetings, minutes from public consultations, media coverage (newspaper, magazines), and additional information from agency websites, as well as websites maintained by public interest groups and non-governmental organizations. Secondary analyses in books and journal articles were also used to further cross-check information.

- Predictive Component

We then use the case cities to test our IIDAPT framework. Based on the seven conditions as measured in each metropolitan area, we predict levels of IIDAPT that should be observed, according to our theory. We then compare the predicted IIDAPT levels in each metropolitan area, to the actual levels that were found. We first compare predicted to actual levels on a case-by-case basis. Although the predicted levels are presented on a qualitative scale from low to high, the actual outcomes are presented as both qualitative descriptions and quantitative measures. Specifically, for the actual levels, we use a summary measure based upon the average level, range and intensity of IIDAPT for ITS and air quality. We then perform a cross-case
analysis in order to identify which of the seven conditions seemed to be the most important predictors of IIDAPT for all of the five cases.

- **Explanatory Component**

The case study approach also has an explanatory component to it. The testing of the framework points us toward the conditions that are the best predictors of overall IIDAPT levels. However, because we use a relatively small set of case cities, we are able to explore the individual cases in depth and with substantial detail. Therefore, having compared the predicted and actual levels, we use the comprehensive case histories (in Chapter 5) to extract deeper explanation from the seven conditions. This involves looking more closely at the mechanisms leading from the individual conditions, to IIDAPT, as well as the possible connections between the conditions themselves (as shown by dotted lines in Figure 1-1).

The case study approach also allows us to place the analysis within the local context of transportation decisionmaking and investments, air quality management efforts and issues, ITS deployment goals and problems, and broader political and organizational agendas and interests. Looking ahead to the findings, we will find that how agencies use ITS as a measure for air quality, depends upon whether it supports efforts to build the case for certain “preferred” categories of transportation investment, both in roadway and transit. In fact, we find that this general pattern holds in spite of the substantial diversity in the five cases analyzed.

1.2.2.4 **Extending the Framework to Mexico City**

In addition to the US case studies, we then take our theory one step further and apply it to the case of Mexico City. We both test the theory with an additional case, but perhaps more importantly, we assess its ability to provide useful policy and technology recommendations to a non-US city regarding how to deploy ITS in a way that is congruent with and supportive of air quality objectives. Given that Mexico City is beginning to deploy ITS more intensively, and the severe air quality problems that this megacity is facing, we hope to provide timely recommendations regarding the use of ITS for air quality improvements. Applying the results of the US case studies to a non-US case clearly provides some additional challenges. However, there are also important insights to be gained from applying this framework to the case of Mexico City. Above all, it will test whether the seven conditions described for the theory of IIDAPT are more broadly applicable outside of the US. It will also test whether we can begin to measure IIDAPT levels for a non-US case.

As will be discussed in Chapter 7, the fieldwork in Mexico City was different from that performed for the US case study cities. While the US case studies involved programmed interviews during site visits ranging from a few days to a week, the author spent over two years living in Mexico City, working on a number of projects related to transportation and air quality management. Formal interviews were carried out during various phases of this research, with earlier interviews (2002-2003) covering broad issues related to transportation and air quality planning and metropolitan coordination, with later interviews (2003 and later) focusing on Intelligent Transportation Systems and air quality.
1.2.2.5 The Appropriateness of the Case Study Approach

The case study approach is appropriate for an area of research where the theoretical basis is limited or incomplete. Our interests lie in explaining under what conditions IIDAPT—a new theoretical construct—will be higher or lower. We will review a large body of literature that provides insights and suggests explanatory variables for the four activities that support IIDAPT—specifically, cooperation, innovation, assessment and adaptation. However, we have used these theories in the construction of a new theoretical framework. Therefore, each “link” between the conditions and IIDAPT (the solid lines in Figure 1-1) has a basis in the existing theory. However, because the concept of IIDAPT, as described in this thesis, is a new contribution, there is no pre-existing full theoretical framework that we can test.

The case study approach provides for a more open-ended and exploratory analysis. It can also form the basis of an iterative approach of theory development and testing, as long as there is rigor in how the theory is structured and outcomes measured. Because the concept of IIDAPT is a new concept being proposed in this research, the case study approach can be used to further refine how this concept is defined and measured. By examining various cases of IIDAPT in different contexts, we can also bound what can and cannot be considered as IIDAPT. Because of the flexibility of the case study approach, it permits a combination of theory building—developing the concept of IIDAPT and identifying conditions that affect it—and theory testing—comparing the predicted and actual IIDAPT levels for five case studies. The flexibility of the case study approach will allow us to build upon our theory testing to further refine the theory by comparing how the conditions we identified performed in predicting and explaining outcomes (or not) and by perhaps identifying additional conditions that may be tested in future refinements of the theory, or eliminating conditions that were poor predictors of IIDAPT. It should be emphasized that these case studies will not serve as a definitive and final test of the theory, nor are they intended to do so. Instead, this is a first test at validating the concept of IIDAPT, the measurement of outcomes, and beginning to identify and measure key conditions that determine IIDAPT levels.
1.3  THEORETICAL BASIS

As noted above, in developing the theoretical framework for IIDAPT, we will draw upon various strands of literature from political science, public administration, and organizational theory, in order to identify the conditions leading to IIDAPT. These conditions will then be tested across our five case studies. Specifically, we look at theories related to innovation, cooperation, assessment and adaptation, described briefly below. This review of the literature and the development of the IIDAPT framework is fully presented in Chapter 4.

1.3.1  Innovation in Government

We are interested in the issue of innovation in government as it relates to the deployment of new technologies by public sector agencies. Theories of organizational behavior are generally pessimistic about the ability of public sector organizations to innovate at all, at least in the absence of crisis (Wilson 1989; Allison and Zelikow 1999). The notion of bureaucracy, as the standardization of processes and procedures, is often presented as antagonistic to the risk taking that is required for innovation. Furthermore, some observers in public administration and public management have raised the issue of whether and under what conditions governments even should try to innovate. The concern here is that innovation can undermine the accountability of public sector agencies (Altshuler 1997).

There has been some attempt in the literature on public administration to identify the factors that lead to innovation, often by those who take a less pessimistic view of the ability of government to innovate. Yet, much of this effort has focused on legislative, policy, and program innovations (Potoski 2001; Sapat 2004). These are interesting approaches in that they focus on state-level innovation within the US federal system, often characterizing the 50 states as laboratories for policy innovation. Some studies have begun to recognize technological innovation, most commonly the use of information technologies, as an important form of public sector innovation (Borins 1998). However, one general critique of the literature on public sector innovation is that the cases used are almost exclusively successful innovations, without providing counterexamples of either unsuccessful innovation or non-innovators.

1.3.2  Cooperation for Multiple Benefits

Government action, on the one hand, requires a certain degree of administrative decentralization of responsibility and power. However, the problem with decentralization and fragmentation of responsibilities is that actual problems do not fit into boxes (Allison and Zelikow 1999). Because we are interested in so-called “win-win” outcomes or mutual benefits in technology deployment – where the objectives of more than one policy “sector” are being fulfilled – this forces us to consider the conditions that can lead to successful cooperation. For technological innovations, and indeed for nearly any other program or policy in the public sector, a fact of administrative life is that successful action often requires coordination with other agencies.

In the area of environmental management in particular, there are often strong calls for policy integration, recognizing that for sustainable development to succeed, other sectors must “take on
board environmental policy objectives” (Lafferty and Hovden 1997). This is a strong statement, and suggests that there needs to be substantially more cooperation than Lindblom’s process of mutual adjustment, in which “every important interest or value has its watchdog” and agencies can either redress damages that may be done by other agencies, or anticipate and head off pending injuries (Lindblom 1959). Indeed, it suggests that agencies from nearly all sectors — transportation, energy, commerce, housing, etc. — should actively seek out and cooperate on policies, programs and projects for mutual benefits. However, as we are warned by Pressman and Wildavsky, implementation, even on programs and projects that seem to have widespread support, can be complicated and even fail due to the complexity of joint action between a large number of agencies (Pressman and Wildavsky 1984).

Cooperation in the area of transportation and air quality, often means overcoming the two-track division of responsibilities between the regulators and regulated, as described by Rip, Misa and others (Rip, Misa et al. 1995). Therefore, the question is whether synergies between multiple policy goals can indeed be achieved, as it implies an alignment of interests between agencies with very different public policy goals. Yet, in order to identify mutual benefits between agencies, we have to go beyond the policy goals of the agencies, and look more closely at their underlying self-interests. The literature of political science on environmental management tells us that if narrow self interests and general interests can align, environmental regulatory stability can be achieved in a way that advances common environmental interests (Oye and Maxwell 1995). The challenge will be to identify the self-interests of the agencies, and separate self-interest from stated policy objectives and organizational missions.

1.3.3 Assessment and Adaptation

If one is concerned with new technologies and their impacts, particularly impacts that are long term and uncertain, it is important to consider the role of the assessment of technologies and their impacts. In theory, by assessing new and emerging technologies, organizations can modify and adapt those technologies in order to improve outcomes. For example, technology assessments, risk assessments, and environmental impact assessments are different mechanisms that have been applied to understand, predict, prevent and/or mitigate the negative impacts — environmental, social, public health, or otherwise — that technologies can create. Others have attempted to bridge the gap between technology policy and technology assessment, espousing an approach labeled “constructive technology assessment” or (CTA). Writers such as Rip, Misa, and Schot, suggest that assessment is part of a broader process of “social learning about how to co-produce technology and its impacts, and how to achieve desirable outcomes” (Rip, Misa et al. 1995). Therefore, in addition to mitigating the negative impacts of technologies, this approach would also support the promotion of technologies with positive impacts.

While this marks the goals for technology assessment, the reality is often one of public sector organizations, struggling with “multiple and vague objectives” (Wilson 1989) with multiple stakeholders to which they must answer. Organizations and individuals also face at least implicit pressures to demonstrate the success of the projects they have so heavily promoted. Therefore, honest assessment that expose the failures of a new technology are difficult to produce. As noted by Wachs, planners are asked on the one hand to “analyze data to discover the truth and to arrive
at the best course of action,” but they are also “advocates” of certain courses of action (Wachs 1989).

There are also different views on adaptation to innovation in response to new information. Adaptation often confronts the same barriers as innovation, in terms of resistance to change by organizations. While there is some literature on regulatory and legislative adaptation to new scientific and technical information (Zuckerman 2001), there is little background on adaptation in the deployment of new technologies in the public sector. This would involve, for example, modifications in the operation of already deployed technologies, changes in the design and deployment of future extensions and expansions of the system, or changes in future decisions about which technologies are to be deployed.

1.3.4 Social Construction of Technologies and Knowledge

Although our set of conditions leading to IIDAPT will be drawn primarily from scholars of political science, public administration, and organizational theory, there is an important undercurrent from the literature on the social construction of knowledge and technologies (Pinch and Bijker 1987). We opened this thesis with a quote from Bijker and Law: “Technologies, we are saying, are shaped. They are shaped by a range of heterogeneous factors. And, it also follows, they might have been otherwise” (Bijker and Law 1992, italics added).

We are interested in the social shaping of ITS technologies, and the social shaping of their impacts on air quality. We want to know if, how, why and under what conditions the public agencies deploying these technologies, actually use ITS for air quality purposes. Observers in the mid-1990s, such as Cervero, Jordan and Horan, and Replogle, offered different visions on ITS, air quality and sustainable communities. We suggest that it is important to keep that broader debate open, and not allow for early closure on the issue of ITS and environmental impacts. Otherwise, we may find, in 50 years, that we have used ITS for an environmentally unsustainable system. And we may ask ourselves, if this system could have been otherwise.
1.4 CONTRIBUTIONS

Through this research, we will contribute to the scholarly literature on innovation in government, cooperation for multiple policy objectives, and assessment and adaptation of technology deployments in the public sector. We also aim to contribute to the practice and policy related to the use of ITS to support air quality objectives.

1.4.1 Scholarly Contributions

We first review the proposed contributions to the literature, highlighting three areas.

1.4.1.1 Technology Deployment as Local Government Innovation

As noted earlier, technology deployment has not been prominent in the literature on innovation in government. This research contributes in identifying factors that lead to technological innovation by local, county and state agencies. It also purposively compares innovators and non-innovators, by choosing cases that were anticipated to be less innovative as indicated by low levels of ITS deployment.

1.4.1.2 Cooperation, Agency Interests and Deployment of New Technologies

Cooperation between government agencies is often seen as critical for achieving environmental policy objectives, but difficult to achieve because of the complexity of joint action. This literature often considers cooperation and agency interests based upon their stated policy objectives and agency missions. On the other hand, in the literature on cooperation for environmental management, there has been a focus on the alignment of public and private interests. This research contributes to these strands of literature by addressing the issue of cooperation between government agencies, but with a focus on the proper identification of public sector agency interests. Specifically, we will see how conflicts between and alignments of agency interests – both the “regulating” and “regulated” agencies – play out in the context of the deployment of new technologies, particularly lower-cost innovations.

1.4.1.3 Role of Assessment and Adaptation in Public Sector Technology Deployments

Finally, we look at assessment and adaptation in the public sector, with respect to the deployment of new ITS technologies by public sector agencies. We will attempt to find patterns in adaptation to the emergence of information regarding new technologies and their air quality impacts. Since public sector agencies are not generally considered as “innovators” or implementers of new technologies, there is even less research regarding how they assess and adapt those technologies in light of new information. Indeed, most of the literature on adaptation of government innovations deals with program evaluation, not technology assessment.

1.4.2 Contributions to Practice and Policy

We now turn to the contributions that are most relevant to issues of practice and policy.
1.4.2.1 How Metropolitan Areas Can and Do Use ITS for Air Quality

To date, there is no comprehensive review of the actual use of ITS for air quality in cities, looking at which technologies are used and how. While there is some literature on how cities can, should, and should not use ITS for air quality improvements, there is little to no empirical work on how cities are, in fact, actually using ITS for air quality purposes. While examples are cited of how cities are using ITS in an environmentally beneficial way, these are often idiosyncratic cases. While they illustrate what can be conceived of as “best practices” in the area of ITS and air quality, they can by no means be considered as representative. In addition to identifying five diverse cases to assess what these cities have actually done with respect to ITS and air quality goals, we attempt to explain the outcomes that were seen in each city. As ITS deployments become more widespread and integrated, understanding these issues will only grow in importance.

We also “assess the assessments” in Chapters 2 and 3. Often, reports and studies of the air quality impacts of ITS are used at face value. However, the analyses of the air quality impacts of ITS are of highly variable quality, and are sometimes misleading in the reporting of the results. These chapters should be useful both for researchers as well as policymakers in order to more critically interpret and use reported air quality benefits from ITS. We will also examine the role of technical and scientific analysis in supporting decisionmaking in a diverse set of cities that are deploying ITS. The question will be whether analysis has reduced uncertainty and highlighted potential tradeoffs in order to make better and more objective decisions, or whether the analysis has been socially constructed in ways that support the interests and objectives of certain players.

1.4.2.2 Improving the Conditions for Using ITS for Air Quality Purposes

This research also has a prescriptive component, in addition to its predictive and explanatory components, described above in Section 1.2.2.3. By identifying the conditions that lead to IIDAPT, we hope to provide policy recommendations on foster higher levels of IIDAPT. Therefore, if the policy goal is to promote greater innovation and experimentation with ITS for air quality improvements, we will provide recommendations for improving the conditions for those outcomes. Because this framework is tested first in the US context, we will generate recommendations for key parts of the US regulatory framework for air quality management and transportation planning – specifically, the air quality-transportation conformity framework, and the Congestion Mitigation and Air Quality (CMAQ) federal funding program.

1.4.2.3 Technology and Policy Recommendations for Mexico City

In Chapter 7, after testing the IIDAPT framework against the case of Mexico City, we also provide a comprehensive set of technology and policy recommendations. First, based upon the discussion of the air quality impacts of ITS technologies in Chapters 2 and 3, we provide recommendations for ITS technologies with the potential to improve air quality outcomes. For these technology recommendations, we take existing ITS deployments in Mexico City as the baseline. We then use the IIDAPT framework, having tested it both for five US case cities and Mexico City, to propose four policy interventions that could be made to improve the
probabilities for successful IIDAPT in the area of ITS and air quality. As opposed to other studies recommending environmentally “sustainable” uses of ITS in developing country megacities, our recommendations are firmly based in an in-depth analysis of the federal and local context of transportation and air quality planning and ITS deployment in Mexico City.
1.5 ORGANIZATION OF THESIS

We have now introduced our research questions and approach, the theoretical basis, and have pointed to the proposed contributions of this research. We have also briefly introduced the concept of Integrated Innovation, Deployment and Adaptation of Public Technologies, or IIDAPT. We now review the structure of the rest of the thesis, and how it relates to the overarching research design, presented in Figure 1-2.

Figure 1-2 Overview of Research Design

Chapter 2 reviews and critiques the existing work investigating the air quality and emission impacts of ITS, focusing primarily on applications for urban passenger transportation – advanced transportation management systems, advanced public transportation systems, and advanced traveler information systems. Chapter 3 then revisits these studies from a different perspective, taking a systems view of how these technologies may interact when deployed at the metropolitan scale. These chapters provide a basis for understanding and identifying potential synergies, as well as tradeoffs, between air quality and mobility when deploying ITS technologies.

We then develop the theoretical framework that will support the remainder of the thesis. In Chapter 4, we review theories from political science, organizational theory, and public administration that take up the issues of innovation, cooperation, assessment of technologies, and adaptation to new information in the public sector – issues that influence the ability to achieve synergies for multiple policy goals through innovation. We then define and articulate our
framework for Integrated Innovation, Deployment and Adaptation of Public Technologies (IIDAPT), and use the theories reviewed to identify seven conditions lead to lower or higher levels of IIDAPT.

Having developed a theoretical framework for the conditions that influence IIDAPT, we then test those conditions using five US cities as case studies in ITS and air quality – Los Angeles, Houston, Boston, Orlando, and Tulsa. The case study histories are presented in detail in Chapter 5, in order to provide the broad context for air quality management, transportation planning and investment, and ITS deployment in each of those cities. Chapter 6 then applies the theoretical framework to each city, to assess to what extent the conditions in each city accurately predicted the actual outcomes observed for IIDAPT.

Finally, in Chapter 7, we test the policy relevance of the IIDAPT framework in a non-US context, while continuing to focus on the technology domain of ITS and its air quality impacts. Looking at the Mexico City Metropolitan Area, we assess the conditions for IIDAPT and, based upon the results of the US case studies, identify possible changes at the federal and local level to better align ITS deployments with air quality goals.

To conclude, we highlight possible areas of future theory development for IIDAPT, and point to additional technology and policy domains where this framework can be further tested, validated and applied.
CHAPTER 2. AIR QUALITY IMPACTS OF ITS: A REVIEW
2.1 INTRODUCTION

Are Intelligent Transportation Systems (ITS) technologies good or bad for air quality? While this is a seemingly simple question, the answer is deceptively complex. The answer depends upon many factors: which pollutant is being considered, the initial conditions of the transportation system, the short- and long-run operational changes brought about by ITS, the characteristics of the vehicle fleet, the mix of ITS applications deployed, and the interactions between those applications. Yet, despite this complexity and uncertainty, many publications tend to downplay the ambiguity regarding the environmental impacts of ITS. As described by the ITS America, the national coalition of ITS professionals:

“ITS helps to optimize trips, eliminate unnecessary travel miles and reduce time spent caught in traffic....Altogether, ITS helps to contain fuel consumption and noxious emissions, reduce dependence on foreign energy supplies and safeguard the quality of the air. The goal is to save a minimum of one billion gallons of gasoline each year and to reduce emissions at least in proportion to this fuel saving.” (ITS America 2002, p 27)

The experience with ITS has been relatively recent, with deployment of ITS in the US only becoming more widespread beginning in the 1990s. While there has been a growing number of studies critically examining the air quality impacts of ITS, it is only enough to ascertain that the jury is still out on the system-level and long-term impacts. Knowledge has improved substantially for some pieces of the ITS-air quality puzzle, such as the effect of changes in acceleration and idling. Other aspects, such as the potential for induced travel, remain relatively unexplored and characterized by assumptions. In practice, many of these uncertainties are ignored in the evaluation of actual ITS deployments. This chapter will review the literature on ITS and environmental quality with the following issues in mind.

- How does ITS improve/degrade air quality?
- Which ITS applications have been shown to have an important impact on air quality?
- Are there ITS applications specifically oriented toward the goal of improving air quality or generating fuel savings?
- When deploying multiple ITS services – often along with conventional infrastructure deployment – how can one unravel the overall air quality impacts?

Given the diversity in the approaches used to measure and estimate emissions impacts, comparing emissions reductions by tons per day or percentage reductions in daily emissions for “X” pollutant, may be misleading. Therefore, in addition to comparing the magnitude of reductions, it is important to focus on the mechanisms by which those reductions are achieved, such as reductions in stop-and-go traffic, increases in speed, mode shifts to public transit or walking/bicycling, or decreases in number of trips or vehicle-miles traveled (VMT). Once having identified a set of key mechanisms for emissions decreases (or increases), we will then integrate those mechanisms within a qualitative systems framework for assessing the air quality impacts of ITS for multiple deployments. This systems framework will be presented in the next chapter.
2.2 ITS AND AIR QUALITY OUTCOMES

In order to guide transportation agencies in their evaluation of ITS deployments, the US Department of Transportation, through its Joint Program Office (JPO) developed a set of measures of effectiveness (MOEs) together with guidelines for how to undertake ITS evaluations. The measures linked benefits to the National ITS Program goal areas of safety, mobility, efficiency, throughput, productivity, and finally, energy and environment.

Table 2-1 National ITS Program goal areas and measures of effectiveness

<table>
<thead>
<tr>
<th>Goal Area</th>
<th>Measures of Effectiveness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Safety</td>
<td>Reduction in the overall crash rate, Reduction in the rate of crashes resulting in fatalities, Reduction in the rate of crashes resulting in injuries, and Improvement in surrogate measures.</td>
</tr>
<tr>
<td>Mobility</td>
<td>Reduction in travel time delay, Reduction in travel time variability (or improved reliability), Increase in customer satisfaction (including product awareness, expectations of product benefits, product use, response, realization of benefits, assessment of value), and Improvement in surrogate measures.</td>
</tr>
<tr>
<td>Efficiency</td>
<td>Increases in effective capacity, and Increases in throughput.</td>
</tr>
<tr>
<td>Productivity</td>
<td>Cost savings, measured as the difference in costs before and after ITS implementation, or the difference in costs compared to a traditional transportation improvement.</td>
</tr>
<tr>
<td>Energy and Environment</td>
<td>Reduction in emissions, Reduction in fuel consumption.</td>
</tr>
</tbody>
</table>

Source: (U.S. Department of Transportation no date)

2.2.1 Energy and Environment

According to the JPO, "the air quality and energy impacts of ITS services are very important considerations, particularly for metropolitan areas that have not attained air quality standards established by the Clean Air Act Amendments of 1990 ("non-attainment areas") (U.S. Department of Transportation no date). Yet, despite this rhetoric, the goal area of “energy and environment” appears to rank low on the priorities of the JPO. For example, while the measures for other goal areas, such as safety, mobility, efficiency, and productivity have additional guidelines, primers, or practical guides, there is little in the way of uniform guidance for measuring and reporting energy and emissions impacts. This lack of additional guidance for documenting environmental outcomes could be due, in part, to the difficulties in measuring or modeling air quality or fuel consumption. However, a review of the federal ITS Program indicated a low level of interest, at least at the federal level, in these objectives during the early years of ITS deployment.

“Among the objectives set forth by the Congress, the one that seems to have received the least attention is the environment. Although some of the travel management projects could benefit the environment, how they might do so is not entirely clear because short-term reductions in traffic and congestion could lead to greater numbers of vehicles on the road, resulting in even greater pollution.” (U.S. Congressional Budget Office (CBO) 1995, p 56).

In addition to showing the low priority given to environmental objectives, this statement also reflects concern about the issue of long-term increases in vehicle volumes, resulting from induced demand, leading to higher levels of emissions, a topic discussed in greater depth in the next chapter. While this review was over a decade ago, there does not appear to have been a major shift in the federal ranking of priorities for ITS, towards environmental concerns. A more recent report by the U.S. Government Accountability Office noted that while ITS could reduce congestion, improve safety and reduce emissions, its deployment, in general, had “fallen short” of early promises across all categories of benefits (U.S. Government Accountability Office (GAO) 2005, p 37).

2.2.2 Air Quality

Within the category of energy and environment, the impacts most frequently cited are those related to ambient air quality, with reductions in fuel consumption typically taking second place, and greenhouse gas emissions a more distant third. Other authors have attempted to place ITS within a broader framework of “sustainable communities,” citing the need to develop indicators and metrics for a wide variety of sustainability concepts, including quality of human life, civic engagement, and quality of the biosphere (Jordan and Horan 1997; Jeon and Amedkudzi 2005). Nevertheless, this chapter will focus primarily on air quality impacts of ITS for several reasons. First, although air quality remains one of the most difficult ITS outcomes to measure, it is more amenable to measurement and modeling than many of the other sustainability indicators. Second, emissions levels can serve as a proxy indicator, albeit incomplete, for a number of other sustainability outcomes of interest, such as energy use, in particular, fossil fuel use, carbon dioxide emissions as a critical component of global climate change and quality of the biosphere, and public health as a component of overall quality of life. Also, since emissions are a function of vehicle miles traveled (VMT), trends in VMT can be a rough surrogate for the level of urban sprawl, and thus loss of habitat, wetlands, and green space. Finally, by critically examining the impacts of one highly important indicator of sustainability, local air quality, this work can perhaps guide future evaluations of the impacts of ITS on other sustainability indicators.

The criteria pollutants regulated by the EPA according to the National Ambient Air Quality Standards (NAAQS) are ozone (O₃), carbon monoxide (CO), nitrogen dioxide (NO₂), lead (Pb),

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7 The work on sustainable development as applied to transportation planning and decision-making in the U.S., shows that issues of the environment and sustainability are treated more seriously by metropolitan planning organizations (MPOs) than by the federal government. Hall, R. P. (2006). Understanding and Applying the Concept of Sustainable Development to Transportation Planning and Decision-making in the US. Doctoral Thesis in Technology, Management and Policy. Engineering Systems Division. Cambridge, MA, Massachusetts Institute of Technology.

8 It should be noted, however, that when citing specific “contributions to sustainability” in Jordan and Horan (1997) the vast majority of the “contributions” are reductions in energy usage and congestion-related emissions.
sulfur oxides (SO\textsubscript{x}), and fine and coarse particulate matter (PM\textsubscript{2.5} and PM\textsubscript{10}).\textsuperscript{9} For this study, we will primarily focus on the contribution of the transportation sector to ozone, and to a lesser extent on carbon monoxide “hot spots.” Particulate matter, unfortunately, has been studied relatively little from the perspective of traffic flow and other ITS-related improvements. This is despite the fact that particulate matter (PM), and specifically fine PM (PM\textsubscript{2.5}) are seen increasingly as critical health risks. With respect to the other pollutants, lead has been reduced dramatically, due to the successful phasing-out of lead from fuels, and SO\textsubscript{x} is generated mainly by industrial sources.

Carbon monoxide is emitted directly from vehicles, as the product of incomplete combustion. The link between vehicle emissions and ambient air concentrations of ozone and PM, on the other hand, is more complex. In the presence of sunlight, ground-level ozone is produced by the interaction of two major components of motor vehicle emissions, volatile organics compounds (VOCs)\textsuperscript{10} and nitrogen oxides (NO\textsubscript{x}) (Molina and Molina 2002, p 7).

\[
\text{VOC + NO}_x + \text{Sunlight} \rightarrow \text{O}_3 + \text{NO}_2 + \text{PAN} + \text{HNO}_3 + \text{particles, etc.}\textsuperscript{11}
\]

Motor vehicles produce exhaust emissions (leaving from the tailpipe and crankcase) from fuel combustion; these so-called tailpipe emissions include CO, VOCs and NO\textsubscript{x}. However, VOCs are also the result of the other type of emissions, evaporative emissions, which are emitted from the tank and fueling system while the vehicle is running as well as at rest (Rakha and Ding 2003). Exhaust and evaporative emissions are dependent upon the characteristics of the vehicle (light or heavy duty, weight, power, age, emissions control equipment and its maintenance), the vehicle’s operating state (cold starts or “hot-stabilized”), the amount of activity (vehicle miles traveled), and the mode of operation (idling, acceleration, deceleration, cruise) (Dowling, Ireson et al. 2005, p 90). While each factor plays an important role in determining emissions, this chapter will focus on the amount of activity and mode of operation – basically, how much the vehicle is being driven and in what manner. As will be discussed below, these two sets of factors can be influenced by Intelligent Transportation System technologies. The difficulty is in moving the level of analysis up from the emissions of a single vehicle, to the emissions of a fleet of vehicles (private cars and trucks, public transit vehicles, and freight vehicles) all interacting on a metropolitan transportation network.

2.2.3 Modeling Emissions and Air Quality

Emissions reductions from ITS applications can be estimated or measured using a variety of approaches, ranging from computer simulations to direct measurements, or using a hybrid

\textsuperscript{9} For more information on the criteria pollutants, see www.epa.gov/air/criteria.html. Last accessed January 19, 2006.
\textsuperscript{10} We will also refer to volatile organic compounds (VOC) as non-methane hydrocarbons (NMHC) or hydrocarbons (HC).
\textsuperscript{11} Peroxyacetyl nirate (PAN) and nitric acid (HNO\textsubscript{3}) are non-criteria pollutants. However, PAN is also an eye irritant and plays a role in smog formation since its thermal decomposition releases NO\textsubscript{2} and an organic radical. Molina, L. T. and M. J. Molina (2002). Air Quality Impacts: A Local and Global Concern. Air Quality in the Mexico Megacity: An Integrated Assessment. L. T. Molina and M. J. Molina. Boston, MA, Kluwer Academic Publishers: 1-19.
approach of simulation modeling along with field measurements for model inputs and/or model validation. Before reviewing the different methodologies and their strengths and weaknesses, the full causal chain is represented in Figure 2-1.

**Figure 2-1 Land-use/transportation/emissions/air quality chain**

Most analyses focus only on the third and forth box in the chain, and the link between them. ITS operational changes fit in the third box of “Transport System Operations Analysis.” Very few analyses take the final step from emissions estimates to air quality forecasting, in which stationary and area sources are added to the emissions mix to forecast air quality outcomes. Usually, the justification is that ITS – at the level of individual projects – will not produce large enough changes in emissions to produce statistically significant changes in the ambient concentrations of pollution. Similarly, land use and travel demand are typically taken to be exogenous, ignoring the feedback loops under the assumption that ITS operational changes cannot be large enough to influence either travel demand or land use. However, the validity of this assumption will be revisited in the next chapter when we discuss the issue of induced travel in more depth.

Therefore, most of the modeling effort lies in improving the interface between the third and fourth box, integrating traffic network simulation and emissions modeling, with some limited incorporation of travel demand models. A review of the state-of-practice in 2001 outlined some of the outstanding issues: (1) “emissions factors...[fail] to adequately capture the effects of vehicle-operating modes on mobile source emissions,” (2) “current travel demand models and traffic flow simulation models are not sufficiently detailed for purposes of ITS evaluation,” and (3) these models “also fail to provide the kind of inputs needed for use in modal emissions modeling” (Mehta, Mahmassani et al. 2001, p 37). Traditionally, traffic network models and emissions models have relied upon average speeds as a key factor linking them, whereas for evaluation of ITS, more refined modeling of starts and stops, idling and accelerations, is needed. Yet, as the quote above illustrates, traffic models (box 3 in Figure 2-1) do not easily produce this level of detail in its outputs, and emissions models (box 4) still cannot adequately accommodate that level of detail for its inputs.

Discerning changes in metropolitan-level or even more localized air quality from an ITS application is complex, although there are efforts in that direction. With current methodologies, the impacts on air quality are difficult to distinguish from the noise created by other factors such as weather patterns, contribution of non-local sources, etc. This difficulty is true for many transportation-related interventions, even major ones like area-wide congestion pricing. For example, in evaluating the air quality impacts of the London Congestion Charging scheme, which had a substantial effect on vehicle volumes and speeds within the charging zone, the “air pollution impact of the scheme has been difficult to assess using ambient measurements alone as
the air pollution concentrations in 2003 were higher than in 2002 because of unusual meteorological conditions" (Beevers and Carslaw 2005). Therefore, nearly all studies will report on the emissions changes, not on the final air quality impacts.

2.2.4 Overview of the Literature

There is a small, albeit growing literature on the air quality and emissions impacts of ITS applications. For example, many of these impacts are documented in the ITS Benefits and Costs database. However, many of the studies on air quality impacts of ITS are found in the “gray literature” or non-peer reviewed articles and reports undertaken by local transportation agencies or their consultants. For this reason, it is often difficult to access the more detailed reports that would provide information on the methodology or models used and the assumptions made.

An additional issue in reviewing these studies is the possibility of biases in the reporting of air quality and emissions benefits. Indeed, the Benefits and Costs Database of the JPO reflects the important organizational goal of promoting the diffusion of information on ITS technologies and their benefits; although this may tend to understate the possible negative impacts of ITS. At the local level, a transportation organization that has already deployed or is about to deploy an ITS application will naturally be more inclined to look for or report positive rather than negative outcomes – across mobility, safety, and the environment – in order to justify costs already incurred in the deployment process. In short, organizations will not be as prone to actively search out negative impacts if they feel that overall the project is beneficial. Alternatively, the reporting of ITS’ environmental benefits may reflect a pre-screening. Projects found to have increases in emissions or fuel consumption, do not have that information reported when included in a transportation plan. Or, these projects are eliminated as possible emission reduction measures in an air quality plan. In both cases, there would be no motivation to report the (negative) emission impacts of these projects.

Indeed, this bias may even enter into the peer-reviewed literature, in particular, the transportation and traffic engineering literature, where there may be more enthusiasm to look for positive results, or “win-win” situations both for mobility and air quality, rather searching for cases where ITS has actually led, or could lead, to a degradation of air quality. There are two forms in which this bias can manifest itself. First, there could be a tendency to report only on those ITS applications with likely positive emissions and air quality impacts, or not to report or measure

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12 This is not to imply that the “gray literature” is necessarily of lower quality. However, it is, in fact, less transparent and accessible, meaning that assessing the quality of the analysis, the methodologies used, and assumptions made is substantially more difficult. The results are therefore less transferable. These issues came up repeatedly during the author’s case study fieldwork. See Chapters 5 and 6.

13 This issue will be discussed in greater depth in Chapters 5 and 6. Also see Chapter 4, Section 4.4.2.4.

14 Although anecdotal, the perceptions of different professional/disciplinary backgrounds were clearly demonstrated in a conference on traffic and transportation engineering. Responding to the author’s presentation on ITS and air quality impacts, the majority of the audience, who were transportation engineers, more readily accepted the possibilities for positive air quality impacts. In contrast, a researcher in environment and public health asked whether gaining transportation efficiency improvements from ITS was simply “rearranging the deck chairs on the Titanic.” See Dodder, R. S. (2004). A Systems Framework for Assessing Air Quality Impacts of ITS: Application to Mexico City. Pan-American Conference of Traffic and Transportation Engineering (PANAM XIII), Albany, NY.
emissions or air quality outcomes if it is anticipated that they will be insignificant or even negative. Second, analysts may focus on changes in only the variables that will lead to reduced emissions, such as less stop-and-go traffic, rather than variables that could increase emissions, such as induced demand from the increase in effective capacity of roadways. This latter outcome is more worrisome, as it can lead to the propagation of misleading analysis. While there are many exceptions to this rule, as will be seen in the studies described below, it is important not to overlook this factor when critically assessing studies on ITS' role in air quality. Given these caveats, we will now review the literature on air quality outcomes of ITS, in order to assess the general state of knowledge in this area.

2.2.5 ITS Functional Areas

ITS applications are commonly categorized into six functional areas. Table 2-2 briefly overviews these six subsystems, their characteristics, examples of applications, and their emissions and air quality impacts.
Table 2-2 Overview of Emissions and Air Quality Impacts by ITS Subsystem

<table>
<thead>
<tr>
<th>Subsystem</th>
<th>Characteristics and Applications</th>
<th>Emissions/Air quality Impacts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Advanced Transportation Management Systems (ATMS)</td>
<td>Network management, including incident management, traffic light control, electronic toll collection, congestion prediction and congestion-ameliorating strategies.</td>
<td>Reductions are possible from reduced congestion and smoother traffic flows. Higher speeds may increase or reduce emissions, depending upon the pollutant and initial/final speeds. Increasing the effective capacity may induce demand, and thus the number of vehicles and VMT, which could worsen long-term air quality.</td>
</tr>
<tr>
<td>Advanced Traveler Information Systems (ATIS)</td>
<td>Information provided to travelers pre-trip and during the trip in the vehicle. ATIS helps provide real-time network information.</td>
<td>Improved route information may reduce emissions through more efficient trip-chaining and congestion reduction, but also may increase overall travel through changes in trip-making behavior, such as more non-peak travel or peak spreading.</td>
</tr>
<tr>
<td>Advanced Public Transportation Systems (APTS)</td>
<td>Passenger information and technologies to enhance system operations, including fare collection, intramodal and intermodal transfers, scheduling, headway control.</td>
<td>Emissions may be reduced through greater use of public transportation rather than private auto use. Operational improvements may reduce emissions from the transit vehicle fleet, by reducing stops, idling and accelerations.</td>
</tr>
<tr>
<td>Commercial Vehicle Operations (CVO)</td>
<td>Technologies to enhance commercial fleet productivity, including weigh-in-motion (WIM), pre-clearance procedures, electronic log books, interstate coordination.</td>
<td>Improved fleet operations may reduce number of vehicles required for given freight movements. May reduce impact on congestion in urban areas. Permits closer monitoring of vehicle performance, fuel use, and emissions.</td>
</tr>
<tr>
<td>Advanced Vehicle Control Systems (AVCS)</td>
<td>A set of technologies designed to enhance driver control and vehicle safety. This ranges up to Automated Highway Systems (AHS), where the driver cedes all control to the system.</td>
<td>Can be used for more efficient driving (e.g., less aggressive accelerations and stops). AHS could dramatically increase effective capacity, leading to increased emissions.</td>
</tr>
<tr>
<td>Advanced Rural Transportation Systems (ARTS)</td>
<td>Mostly safety and security technologies (e.g., May-day) for travel in sparsely settled areas.</td>
<td>Not applicable</td>
</tr>
</tbody>
</table>

Source: Definitions and Characteristics, (Sussman 2000, p 326); Emissions/Air Quality Impacts, Author.

We will survey the state of knowledge on air quality and emissions impacts of ITS for three of these subsystems—ATIS, ATMS, and APTS—thus focusing primarily on urban, and not rural/intercity transportation, and on passenger transportation rather than freight. Emissions estimates are based on a variety of approaches, including analytical methods, simulation models, field measurements, or combinations of the above. Examples of each method and the differences in their results will be highlighted.
2.2.5.1 Advanced Traveler Information Systems (ATIS)

One approach to estimating the emissions reductions from ATIS is to develop quantitative analytical models based upon queuing theory, then to use these models to test out different scenarios with and without the traffic information provided by ATIS. Although these models are theoretical in nature, they often require real-world information on emissions rates (grams/mile or grams/hour for idling emissions). These emissions factors can be derived from the EPA’s mobile source emissions factor model MOBILE, using assumptions on average speeds, fleet mix, Inspection and Maintenance (I/M) programs, deterioration of emissions control equipment, temperature, altitude, and other factors specific to the metropolitan area being studied. In addition to MOBILE, there are other advanced models such as EMFAC (California’s emissions factor model) and CMEM (Comprehensive Modal Emissions Model for light duty vehicles).

As an example of this approach, Al-Deek et al used a deterministic queuing model of a corridor with two routes to calculate emissions under different scenarios for incidents with and without ATIS-based re-routing of traffic from the incident route to the alternate route (Al-Deek, Wayson et al. 1995). Emissions factors for idling emissions and moving emissions were derived from MOBILE5a. They found that although emissions would increase for the route to which traffic was being diverted, at the corridor level, overall emissions would be reduced through the use of ATIS. Furthermore, emission reductions, at least for CO and VOCs, were found to be more significant with higher market penetration rates for in-vehicle ATIS. For NOx emissions, a small market share seemed to provide enough congestion relief on the incident route to reduce idling emissions and therefore lower NOx emissions. Yet, higher market shares could actually lead to increased NOx levels because of higher speeds (greater than 29 mph) and vehicles being re-routed to faster but longer routes, therefore increasing total VMT (Al-Deek, Wayson et al. 1995, p 383).

There have also been studies based upon simulation models to assess air quality outcomes of ATIS. One recent study (Kaysi, Chazbek et al. 2004) used a dynamic traffic assignment model (DYNASMART)\(^{15}\) to estimate travel times, speeds, stops and queuing on a link-by-link basis, at short time intervals, for an entire network. For emissions, the Motor Vehicle Emissions Inventory (MVEI) model, developed by the California Air Resources Board, was used to determine emissions factors for the fleet. Looking at the case of Beirut, Lebanon, they tested several scenarios for incidents and pre-trip and in-vehicle information, and with different levels of compliance\(^{16}\) with information (10, 20, 50 and 90 percent). In all scenarios where information was used as an incident management strategy, CO and VOC emissions were lower than without

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\(^{15}\) DYNASMART-P (DYnamic Network Assignment Simulation Model for Advanced Road Telematics) was developed at the University of Texas at Austin. According to Dowling et al, this is a mesoscopic model which "simulates individual vehicles, but it assumes that all vehicles travel at the same average speed" Dowling, R., R. Ireson, et al. (2005). Predicting Air Quality Effects of Traffic-Flow Improvements. National Cooperative Highway Research Program (NCHRP) Report 535. Washington, DC, Transportation Research Board.

\(^{16}\) The implicit assumption is that all drivers have access to this information both pre-trip and in-vehicle. The use of "compliance levels" by Kaysi et al (2004) is analogous to market penetration, where only a fraction of the drivers have access to this information, for example, in-vehicle navigation systems, but may use the information the majority of the time.
information, although after a certain level of compliance, “overreaction” to traffic information led to congestion of the incident-free alternate routes. Nevertheless, in contrast to Al-Deek et al (1995), it was found in the case of Beirut that reducing idling times could actually increase emissions, according to the authors because NOx idling emissions are lower than emissions at high free-flow speeds. With “shorter queues, less idling, and more traveling cars... NOx emissions increase” (Kaysi, Chazbek et al. 2004, p 7). In fact, as shown in Figure 2-2, NOx emissions were higher with information under all levels of compliance.

**Figure 2-2 Emissions and Travel Time Changes with Incident Information**

![Figure 2-2 Emissions and Travel Time Changes with Incident Information](image)

*Percentages refer to levels of compliance with both pre-trip and in-vehicle information
Source: (Kaysi, Chazbek et al. 2004, Table 3)*

Although the focus was on the use of ATIS to improve network conditions during incidents, an important result from the modeling work is that pre-trip and in-vehicle information with no incident (i.e. under normal traffic conditions), improved network performance and substantially reduced travel times and stops, even at 20% compliance rates. Yet, this “better use of the network capacity... induced longer vehicle-miles traveled and thus higher total emissions” (Kaysi, Chazbek et al. 2004, p 8). While the term “induced” is used, this is not what is commonly called “induced demand,” since this model was not linked to a demand model. We will discuss the phenomenon of induced travel in the next chapter.

An earlier study completed by Tech Environmental (1993) also looked at better traveler information under normal traffic conditions. This study attempted to estimate the potential impacts of SmarTraveler in Boston, a phone-based ATIS service where drivers can call to access real-time information on conditions for specific routes. Based on a rather optimistic assumption that 30% of the daily callers would either change their travel route, departure time, or travel mode based upon the information they received, the reported daily emissions reductions for “participating drivers” were substantial for VOC (25%) and CO (33%), but marginal for NOx
(1.5%) (Tech Environmental Inc. 1993). However, it is uncertain to what extent impacts on overall traffic flows were measured as part of the study, since the reported results only identified changes in emissions from changes in travel by those using the service, which represents a very number of overall trips (28,800 daily trips).

Although there are relatively few studies available to reach a definitive conclusion about the effectiveness of ATIS on air quality, the indications are that the impacts on air quality are positive for VOCs and CO, but more uncertain for NOx. The benefits for VOCs and CO are generally more significant, and hold across a range of congestion levels and ATIS market penetration and compliance levels. For VOCs and CO, emissions factors are substantially higher at lower speeds, and fall continuously with increases in speed, until reaching speeds above 40 or 50 miles per hour (depending upon the fleet characteristics and emission factors that one is using, see Figure 2-3 and Figure 2-4). Therefore, reducing travel at lower speeds is generally beneficial for VOC and CO reductions. NOx reductions, on the other hand, are more difficult to attain. The slope of the emissions factor curve is relatively flat at lower speeds, meaning that reducing travel at lower speeds does not substantially affect NOx emissions. Yet, NOx increases steadily above speeds around 30 mph, and emission factors at high speeds (65 mph) are actually higher than emission factors at very low speeds (5 mph) (for example, see Figure 2-4). The opposite is true for VOC and CO.

**Figure 2-3** MOBILE emissions factors for CO, NOx and HC by speed (g/mi)
Although it is important to consider what emission factors are used, modeling approaches can make an important difference in results. As noted earlier, Al-Deek et al (1995) suggest that reductions of NOx through idling reductions can be made, although they might be then offset by increases of NOx at higher speeds and possibly due to higher VMT due to rerouting. However, Kaysi et al (2004) provide a slightly different set of conclusions, suggesting that since NOx emissions during idling are much lower than emissions at corridor speeds of 30-35 mph, almost any improvement in traffic flow will increase NOx. One might expect that the difference in their results derives from the emissions factors they used, and that the emissions factors used by Kaysi would be much higher at free-flow speeds, than when idling, compared to Al-Deek. Yet, in Kaysi et al (2004), free-flow emission factors are 5.4 time higher than idling emission factors, while for Al-Deek et al (1995), free-flow emissions are 9.4 times higher than idling emissions. Thus, the actual difference seems to stem from the modeling approaches and underlying conceptual frames used by each group of researchers. While the non-linear function for NOx emissions factors does greatly complicate the task of estimating emissions outcomes, this shows that results may be more sensitive to the choice of a modeling approach than to the choice of inputs (such as emissions factors). It further suggests that any estimates of emissions reductions should be looked at very carefully.

17 Converted into grams per minute for comparison, Al-Deek et al (1995) uses 0.17 g/min (for idling), 1.55 g/min (at 35 mph), while Kaysi uses 0.25 g/min and 1.34 g/min, respectively.
Although not addressed in these studies, the impacts of ATIS also depend on the severity and duration of the incident. Both Kaysi et al and Al-Deek et al assumed a constant duration for the incident (60 minutes in the case of Kaysi). In an evaluation of San Antonio’s traveler information web page, the use of the information led to both higher speeds of travel and travel time savings, with these benefits increasing as the severity of the incident moved from minor to moderate to major (Carter 2000). However, when there were only minor incidents, the rerouting of traffic from freeways to arterial streets (with traffic signals) meant an increase in both the average number of stops per vehicle and average fuel consumption. Although not measured in this evaluation, it is plausible that emissions also increased when incidents were only minor, perhaps at a greater rate than fuel consumption because of the greater number of accelerations on arterial streets.

Market penetration is another key variable for ATIS when evaluating air quality impacts. At small market penetration rates (measured as the number of vehicles equipped with navigation or traveler information systems, or the daily number of callers compared to daily total trips in a region) there may be emissions reductions for the users of the information service, as they use less congested routes. Yet, the overall impact on traffic may be negligible. With greater market penetration, overall traffic flow improvements and emissions reductions may be greater, although with the possibility of NOx increases from higher speeds.

Finally, there is a deficit of studies looking at the air quality impacts of multi-modal traveler information, which would integrate information on traffic conditions with static and real-time information for public transportation. One of the most outstanding examples of a multi-modal ATIS is that of the San Francisco Bay Area’s 511 service. The web and phone-based service provides integrated information on traffic, transit, bicycling and ridesharing. Some of the features include real-time traffic information, transit trip planning, some real-time transit arrival information, online rideshare matching, current vanpool availability, park-and-ride lot information, the interactive 511 BikeMapper, and links to City CarShare.18

The SmarTraveler study reports to have included mode share outcomes. Yet, because only the summary of the study’s results could be accessed, it is not clear what modeling assumptions were made (MITRE Corporation 1996, p 10). The question of mode share change deserves greater study, since the emissions impacts from mode switching – specifically from private autos to public transit, ridesharing, bicycling or walking – could represent the most significant long-term air quality benefit by actually removing vehicles from the road, and thus reducing VMT. Yet, the ability of ATIS to generate mode shifts also depends on the ability of the alternative modes – such as underground subway, light rail, Bus Rapid Transit systems (BRT) with dedicated bus lanes, and carpooling/vanpooling with access to faster high-occupancy vehicle (HOV) lanes – to provide shorter travel times.

18 See 511.org for multi-modal traveler information in the San Francisco Bay Area. Currently the real-time transit information is only available for Muni (San Francisco Municipal Railway) service. See www.nextmuni.com. Last accessed August 1, 2006.
2.2.5.2 Advanced Transportation Management Systems (ATMS)

Under the heading of ATMS are ITS applications aimed at improving traffic flows on both freeways and arterials. These systems include traffic signal control for arterial networks, ramp metering or electronic toll collection (ETC) on freeways, as well as applications which can be applied to both arterial systems and freeways, for example, incident management systems or variable message signs.

- Advanced Traffic Signal Control

Improved traffic signalization is perhaps the most widely deployed of the ITS applications. This can involve optimization of signal timings at individual intersections, signal synchronization along a specific corridor, signal coordination across jurisdictions, advanced signal control using a centralized control center, or even adaptive signal control with real-time signal strategies developed in response to current traffic conditions. As will be seen in Chapters 5 and 6, this is also one of the ITS strategies most commonly used by metropolitan areas for emission reductions. There is a relatively large amount of literature (both in the peer reviewed and “gray” literature) on the fuel and emissions impacts of improvements in traffic signalization, due in part to the large number of projects classified as Transportation Control Measures (TCMs) within air quality plans, or undertaken with federal funds distributed through the Congestion Mitigation and Air Quality (CMAQ) Program. Many of these studies suggest moderate emissions reductions from ITS-based improvements to arterial traffic flows. Yet, as will be discussed, several methodological hurdles must be overcome, both in terms of the level of modeling detail required to accurately estimate emission changes, as well as the scope of the analysis, in terms of incorporating all relevant factors, short-term and long-term, into the analysis.

Results from real-world applications tend to point toward moderate emissions reductions for the study areas. Traffic signal optimization of 700 intersections in the Tysons Corner Network in Virginia, outside of Washington, DC, suggest the potential to reduce fuel use by 9% and reduce CO, NOx and HC emissions by 134,600 kg annually. Retiming and coordination of 900 signals in Oakland County, Michigan claimed benefits in reductions of CO, NOx and HC roughly on the order of 2-4% (Halkias and Schauer 2004). In Syracuse, New York, a network simulation of 37 of the 145 interconnected and optimized intersections produced estimates of average vehicle emissions during both the AM and PM peak period, as well as the mid-day period. Substantial emissions reductions were reported, between 9% and 13% for the study area. While these results appear promising, they should also be interpreted with caution.

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20 The full study could not be accessed, therefore it is not clear what the relative emissions reductions of CO, NOx and HC were. It is assumed that the majority of the 134,600 kg total annual reductions were CO reductions, which are emitted at larger rates (grams/mile) than NOx or HC.
21 The results are cited on the JPO’s online benefits database. The study was carried out by DMJM Harris in cooperation with the New York State Department of Transportation. See www.itsbenefits.its.dot.gov/its/benecost.nsf/ByLink/BenefitsHome. Last accessed January 23, 2006.
Table 2-3 Reported emissions changes for Syracuse signal interconnect project

<table>
<thead>
<tr>
<th></th>
<th>AM Peak Period</th>
<th>Mid-Day Period</th>
<th>PM Peak Period</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Before</td>
<td>After</td>
<td>% change</td>
</tr>
<tr>
<td>Fuel Use (gallons)</td>
<td>490</td>
<td>447</td>
<td>8.8%</td>
</tr>
<tr>
<td>CO (kg)</td>
<td>34.24</td>
<td>31.27</td>
<td>8.7%</td>
</tr>
<tr>
<td>NOx (kg)</td>
<td>6.66</td>
<td>6.08</td>
<td>8.7%</td>
</tr>
<tr>
<td>VOC (kg)</td>
<td>7.94</td>
<td>7.25</td>
<td>8.7%</td>
</tr>
</tbody>
</table>

Source: (DMJM Harris 2003)

Reviewing Table 2-3, it can be seen that the emissions reductions for the three pollutants are scaled almost exactly to the reductions in fuel use. The software package used to produce the emissions estimates, SYNCHRO, simply applies an adjustment factor to fuel consumption to estimate changes in NOx, CO and HC (Rouphail, Frey et al. 2001). Yet, this approach fails to take into consideration the non-linear nature of emissions changes with respect both to speed and to the number and duration of stops and acceleration events, and therefore is likely to overestimate or underestimate emissions reductions from speed improvements, depending on which pollutant is considered, and where on the emissions factor curve the improvements are being made (see Figure 2-3 and Figure 2-4). Therefore, by indirectly estimating emissions from fuel use, rather than calculating emissions directly from change in speeds or idling, can be deceiving, particularly when the results are presented with a supposed accuracy of hundredths of kilograms.

Compared to traffic signal retiming, coordination, synchronization, and centralized control of traffic signals, there is relatively less information on adaptive signal control systems in the US, in part, because the transportation community in the US tends to perceive less advantage from adaptive signal control, compared to a well-timed signal timing plan (U.S. Department of Transportation 2000, p 50). However, a study of adaptive signal control strategies in Toronto points to modest reductions in pollution emissions (3-6%) and fuel consumption (4-7%) (Greenough and Kelman 1999).

The analysis by Skabardonis (2004) is valuable in that he examines the fuel savings benefits of three types of signal control improvements: signal coordination, signal optimization of already coordinated signals, and traffic responsive signal control (or adaptive control systems), across a large number of projects. For example, for signal timing optimization, data from California’s Fuel Efficient Traffic Signal Management Program (FETSIM) was used. The FETSIM program provided financial, technical and training support to 163 local agencies (154 cities and nine counties, between 1983 and 1993) for a total of 334 projects. Benefits, in terms of reductions in travel times, delays, stops and fuel use, were both modeled as well as measured in the field for 163 individual projects (a total of 6,701 signalized intersections) (Skabardonis 2004). TRANSYT is a macroscopic model used both for simulation as well as for the actual

22 Indeed, the two most well established adaptive control signal systems were developed in Australia (SCATS – Sydney Coordinated Adaptive Traffic System) and the United Kingdom (SCOOT – Split, Cycle, Offset Optimization Technique).
optimization of the signal timing plans. For the FETSIM projects, TRANSYT was used to first to simulate existing conditions for the arterials or grid systems, then to optimize the signal plans, and finally to estimate the resulting benefits from the optimized plans. In addition to the TRANSYT simulation modeling, "before-and-after" field studies were conducted using floating cars to sample travel times, delays, and stops. The results of the field studies supported the modeled results. An interesting outcome of the TRANSYT analysis is that the benefits in fuel savings followed travel time improvements linearly, with every 1% of travel time savings resulting in a 1% saving in fuel use (with savings up to approximately 25%). However, the fuel savings results from the FETSIM Program should not be generalized to other cases of signal optimization, since the signals were optimized with fuel consumption as one of the key criteria for selection of the "best" timing plans. Finally, although Skabardonis points to air pollution reductions as being an additional benefit (of particular importance in non-attainment areas), unfortunately, neither the simulation modeling or field studies provide specific data. Unlike the DMJM Harris study undertaken for the city of Syracuse, no attempts are made to extrapolate emissions reductions from fuel savings.23

In a recent National Cooperative Highway Research Program (NCHRP) report "Predicting Air Quality Effects of Traffic Flow Improvements," a five-module methodology was developed in order to overcome many of the current methodological shortcomings, as well as estimate the long-run impacts (to the year 2020) of traffic flow improvements. The methodology was intended to be both rigorous enough to capture the effects of changes from a range of traffic-flow improvements - including ITS and more traditional projects - but practical enough to be within the capabilities of most medium and large city MPOs (Dowling, Ireson et al. 2005). It also incorporates effects not modeled in the majority of the studies reviewed, such as: "the impact of travel time changes on trip making by peak period and by mode of travel,... [and] the impacts of traffic-flow improvements on growth patterns" (Dowling, Ireson et al. 2005).

Applying this methodology to predict the effects of coordinating six signals along a 0.54 mile arterial in Seattle, showed a possible increase in speeds of 9%, a regional VMT reduction by 0.01% and regional emissions reductions of NOx (0.02%), CO (0.03%) and HC (0.04%) compared to the 2020 base case (Dowling, Ireson et al. 2005). Although these effects are extremely small, it should also be kept in mind that the project length modeled for the signal coordination was only a half mile, and were the same order of magnitude as other transportation system changes such as adding an HOV lane or park-and-ride lots.24 This is also one of the few studies looking at the long-term impacts of ITS-based traffic flow improvements. Given the relatively small size of the projects modeled and the uncertainty in this type of long-run analysis, these results should be considered more as indications than predictions. Nonetheless, the results


24 The only transportation system project modeled with the NCHRP 25-21 methodology that had a more substantial impact on regional emissions in 2020, was the addition of a lane on an urban freeway, which increased regional emissions by 0.37% (NOx), 0.28% (CO), and 0.19% (HC). Dowling, R., R. Ireson, et al. (2005). Predicting Air Quality Effects of Traffic-Flow Improvements. National Cooperative Highway Research Program (NCHRP) Report 535. Washington, DC, Transportation Research Board.
show that reductions of CO, NOx and HC can be achieved by increasing arterial facility speeds while slightly reducing regional VMT. Although not discussed the report, the lower VMT could reflect drivers using the optimized arterial facilities as more direct routes (hence, lower VMT), rather than taking slightly longer trips in order to make use of higher speed freeways.

- Ramp Metering

The Twin Cities of Minneapolis and St. Paul, Minnesota boast one of the extensive deployments of ramp control in the world, making it an important case for assessment of air quality benefits for this ITS application. In 2000, a simulation study was carried out by researchers from the University of Minnesota, in order to assess the impacts of ramp metering along two freeway sections (Hourdakis and Michalopoulos 2002). The first section, Trunk Highway 169 (TH-169) is a circumferential freeway with relatively low traffic volumes, while the second section chosen is a segment of Interstate 94 (I-94), which has higher traffic levels and often severe peak hour congestion. The AIMSUN (Advanced Interactive Microscopic Simulator for Urban and Non-Urban Networks) microscopic traffic simulator was used to assess ramp metering using several measures of effectiveness (MOEs) that were expanded to include measures of interest to the public. The simulator was interfaced with the ramp control logic actually used by the Minnesota DOT, and used data collected by detectors for the tested freeway sections.

Interestingly, since ramp metering was already in place, the simulation was conducted in order to see the impacts of shutting off the ramp meters, making the existing ramp metering configuration the base case. The simulation results indicated that both fuel consumption and pollutant emissions would increase significantly without ramp control, primarily due to the traffic smoothing impacts on the mainline freeway, which reduced the number of acceleration-deceleration cycles. The results for the less congested freeway (TH-169) are shown in Table 2-4.

<table>
<thead>
<tr>
<th>Freeway Freeway Fuel</th>
<th>Pollutant Emissions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed (mph)</td>
<td>Stops (total)</td>
</tr>
<tr>
<td>With Ramp Control</td>
<td>56.2</td>
</tr>
<tr>
<td>Without Ramp Control</td>
<td>46.5</td>
</tr>
</tbody>
</table>

| % Change | 17% | 2011% | 34% | 18% | 13% | 25% |

*Fuel consumption and pollutants include entire site, both on the mainline freeway and ramps
*"% Change" represents the simulated impacts of shutting off ramp control
*Results are for northbound TH-169, on March 21, 2000 from 14:00-20:00

Source: (Hourdakis and Michalopoulos 2002), Table 2

25 The authors note that the study was partially motivated by the need to demonstrate the benefits from the system, due to some public dissatisfaction with its performance, in particular, long queuing times at certain on-ramps.
Despite the fact that through ramp metering, freeway speed would increase from 47 to 56 mph, the turning point at which NOx emissions factors (grams per mile) often begin to increase rapidly, NOx emissions are actually 25% lower with ramp control. This suggests that for this case, the reduction in stop-and-go traffic overshadows speed increases in terms of its overall impacts on NOx emissions, by reducing acceleration/deceleration cycles on the freeway mainline. The selected results presented in Hourdakis and Michalopoulos (2002) (and shown in Table 2-4) are only for the smallest speed changes between the control and no-control cases. At higher speed differences, the reductions in NOx could be diminished, or NOx could even increase, due to the sensitivity of NOx emissions factors to increasing speeds.

Although most other ITS-based traffic flow improvements tend to show lower reductions for NOx than for CO and HC, these results for ramp metering coincide well with most studies focusing on acceleration events, and more specifically, the “power enrichment” or “fuel enrichment” events which occur during sustained and hard or aggressive accelerations (see Figure A-1, Figure A-2, and Figure A-3). Under these conditions, the vehicle fuel delivery system increases the fuel/air ratio, leading to higher CO and VOC emissions than would occur at cruising speeds (Dowling, Ireson et al. 2005). However, NOx emissions rates are somewhat less sensitive to acceleration, with speed being the determining factor of NOx levels (Rakha and Ding 2003).

• Electronic Toll Collection (ETC)

There have been numerous studies looking at the air quality benefits of ETC. In part, this is due to the relatively localized nature of ETC, since one can usually confine the analysis to a specific toll plaza or group of toll plazas rather than assess impacts spread out over an entire network. Emissions reductions have been assessed for ETC applications in the Chicago area (Sisson 1995), the Carquinez Bridge in California (Gillen, Li et al. 1999), the New Jersey Turnpike Authority E-ZPass system (Wilbur Smith Associates 2001), Baltimore (Saka, Agboh et al. 2001), Orlando (Klodzinski, Al-Deek et al. 1998), and Oklahoma (MITRE Corporation 1996, p 14). Saka et al (2001) combined a traffic microsimulation model with the Mobile 5b emissions model to measure emissions from the Fort McHenry Tunnel toll facility, the largest toll plaza in Maryland. Two scenarios were developed: (1) the baseline, with all toll lanes operating manually, and (2) an ETC market penetration of 28%, with two exclusive ETC lanes (although the ETC-equipped vehicles could use ETC or manual lanes). Despite the limitation that MOBILE 5b is not capable of reflecting the full drive cycle of vehicles at toll plazas - stops, decelerations, and accelerations - they used this emissions model due to its role as the “only accepted method of determining air quality compliance in nonattainment areas” (Saka, Agboh et al. 2001, p 328). As a result, only changes in the weighted average speed for the entire toll facility (weighted according to the flow in each direction) were used in the emissions modeling. Comparing these two scenarios, the scenario with 28% market penetration of ETC (which

26 AIMSUN calculates emissions using look-up tables that give pollutants (HC, CO and NOx) in grams/second for each speed-acceleration/deceleration category and by vehicle class. See http://www.aimsun.com/faq_env.html Last accessed May 19, 2005. The changes in emissions are for the “entire site,” and thus should also include emissions from waiting on the ramp.
corresponded to the observed use at the time) generated reductions in emissions of 11% (0.85 kg) for NOx, 40% (3.77 kg) for HC, and 41% (36.04 kg) for CO, at a weighted average speed of 18.6 km per hour.

While this analysis gives a rough indication of the emissions reductions, there are two important limitations. One limitation, as already mentioned, is the use of MOBILE 5b emissions factors, which do not capture emissions during stops and accelerations. Decelerations are usually not important events from the emissions standpoint. Conversely, the highest emissions generally occur during accelerations (Rouphail, Frey et al. 2001). The other limitation is the use of average speeds for each direction, which does not differentiate between slow-moving manned lanes and fast-moving automated toll lanes, or between ETC and non-ETC equipped vehicles. By using average speeds to derive emissions rates, the study might not properly reflect the actual emissions rates from vehicles moving at various speeds, both higher and lower (see Figure 2-3 and Figure 2-4).

Sisson (1995) took a different approach to measuring the air quality effects of ETC, focusing on the number of acceleration events (from 0 to 65 mph) rather than changes in average speeds. He stated that “traditional toll collection adds to a region’s air quality problems by introducing a number of additional accelerations from a full stop to high speed during a tollway trip,” adding that “the California Air Resources Board (CARB) determined that one hard acceleration from rest to freeway speed may release as much pollution as over three miles of average driving” (Sisson 1995, p 93). This is consistent with a protocol developed for the Northeast States for Coordinated Air Use Management (NESCAUM), which calculated that a speed profile of 65-0-65 mph over a distance of 0.55 miles produced emissions equivalent to driving a steady 65 mph for 3.3 miles for HC, 1.98 miles for CO, and 1.01 mile for NOx (Roberts and Shank 1995). Looking at three possible levels of ETC usage in the Chicago area (25, 50 and 75 percent market penetration), he estimates the annual reductions in emissions by eliminating accelerations for those vehicles using ETC. While the focus on accelerations is useful, Sisson made assumptions regarding emissions factors that might not be valid. Based upon emission factors from CARB for grams emitted per 0-65 acceleration (for model years 1989 and 1990), Sisson then adjusted those factors for older vehicle model years to get a fleet average. One potential problem is the use of emissions factors based on average speed to scale up emissions factors based on accelerations. As briefly discussed earlier, the recent work by Rakha and Ding (2003) shows that the relationship between speed and acceleration is substantially more complex. Specifically, it is non-linear. For older vehicles, the emissions factors curves may have steeper slopes for emission rates at low and high speeds. Finally, Sisson did not take into account the possible improvements to the non-ETC equipped vehicles by freeing up manual toll lanes, and therefore increasing speeds at manual lanes and reducing queues.

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• Incident Management

Relatively few published studies have been carried out to estimate the emissions impacts of improved incident response strategies. The primary mechanism for achieving emission reductions from improved incident response is the reduced duration of incidents and traveler delay, and therefore reduced buildup of congestion and the resulting stop-and-go travel conditions. In San Francisco, a freeway service patrol, deployed under the auspices of the federal Congestion Mitigation and Air Quality (CMAQ) Program, reports daily reductions of 32 kg of HC, 322 kg of CO, and 798 kg of NOx (U.S. Department of Transportation 1996). However, because each incident is different in terms of the location, number of lanes affected, both by closure and by “rubbernecking” of passing drivers, and the severity and duration of the incident, there are no equivalent controlled conditions as in the case of ramp metering or ETC to provide for easy simulation modeling or field measurements.

Looking at the San Antonio TransGuide System, which includes 26 miles of downtown freeway, Henk and Molina (1997) used before (1992-4) and after (1995) data to compare the impact of the incident management system on crashes and incident response time. Reductions in response times, collected from video surveillance data, were used as input into CORFLO, a corridor simulation model. For a major incident, there was an average delay savings of 700 vehicle hours and fuel savings of 2,600 gallons (Henk and Molina 1997). However, emissions reductions from the delay savings were not reported.

The small number of studies on air quality impacts of incident management leaves a significant analytical gap in understanding the impacts of ATMS on air quality, since it focuses on non-recurrent, incident-based congestion instead of recurrent congestion. Improvements to non-recurrent congestion may reduce travel time variability (and thus improve reliability) without actually reducing average travel times. As a result, the potential for induced travel from managing non-recurrent congestion is less clear. However, since ITS-based improvements through ATMS will improve levels of service, there are still possibilities for induced travel. We will consider this issue at greater length in the next chapter.

2.2.5.3 Advanced Public Transportation Systems (APTS)

The assessment of air quality benefits of APTS has been relatively limited to operational improvements in advanced transit fleet management through ITS. Many of the other categories of ITS applications such as safety and security, information dissemination and transit fare payment (smart cards), have not been evaluated for their air quality benefits, despite their potential to attract more riders from private automobiles, thereby reducing VMT.

• Transit Signal Priority

Transit Signal Priority (TSP) – the preferential treatment given to transit vehicles at signalized intersections – provides the means to improve transit operations and level of service. Signal

priority can be “passive” in that signal timings are set to favor transit vehicle speeds (to account for dwell times at stops) rather than the speed of general traffic, or “active” meaning that strategies – an early green or green extension – are only implemented when a TSP-equipped vehicle approaches the intersection (Baker, Collura et al. 2002). Understanding the effects of TSP on emissions requires modeling the changes in the operation of the transit vehicles given priority, and the effects of signal pattern changes on all vehicular traffic, in particular, cross-street traffic, and finally, the possible changes in ridership from improved transit service.

Using a micro-simulation model, INTEGRATION, Dion et al analyzed the potential impacts of transit signal priority along a corridor in Arlington, Virginia. INTEGRATION simulates traffic using time intervals of 1/10th of a second, therefore allowing emissions to be estimated using instantaneous speed and acceleration data. Various scenarios were run to assess the outcomes of giving priority to express buses, regular buses, and cross-street buses along the corridor. According to the authors, “in terms of environmental impacts, the simulation results do not provide conclusive trends” (Dion, Rakha et al. 2003, p 301). The effects of transit signal priority on HC, NOx and CO were modeled by taking into account changes in emissions by all buses – express, regular (arterial) and cross street – and all other traffic both along the corridor and from cross streets. Most emissions changes were less than 1% and not statistically significant (Dion, Rakha et al. 2003). Even in scenarios where vehicle stop times and overall travel times were reduced, no clear-cut emissions reductions or increases were found. This is because the model was able to capture the behavior of individual drivers and variations in their speeds.

The authors warn against applying the results of the study to other areas, since the outcomes greatly depend on the corridor or network being studied (Dion, Rakha et al. 2002). Furthermore, the analysis used a relatively simple logic for granting priority to transit. More advanced TSP strategies could be used to maximize the benefits to the transit vehicles while minimizing disruptions to general traffic – for example, giving “conditional” priority to transit vehicles depending upon their schedule adherence (late or early), number of passengers (from Automated Passenger Counters), and traffic conditions such as levels of delay on cross streets.

The strength of this analysis lies in the level of detail in modeling the dynamics of both transit vehicles as well as the complex dynamics of general traffic flows, and the ability to capture the emissions impacts of both speed and acceleration. However, as just noted, a limitation is the relatively simple TSP logic applied.

* Service Quality Improvements

The studies by Dion et al (2003) focused on improvements from TSP and their potential emissions effects. However, in many cases, multiple ITS applications are implemented together, often taking advantage of the detailed real-time information provided by GPS and other Automatic Vehicle Location (AVL) systems. For example, Lehtonen and Kulmala (2002) provided a comprehensive evaluation of the deployment of AVL, real-time passenger information at transit stops and inside vehicles, conditional signal priority to vehicles running behind schedule, and Computer Aided Dispatch (CAD). Their assessment of overall benefits included a combination of field measurements of operational performance, interviews and
surveys of passengers and operators, simulation, and socio-economic evaluation. However, the simulation of the effects of ITS on emissions was limited in scope. For estimating emissions, it was assumed that the “only difference between the before and after situation in the simulation is the length of time which the buses are standing still at stops or signals” (Lehtonen and Kulmala 2002, p 6-7). Therefore, only the difference in idling emissions was calculated, while the dynamics of the bus in motion were assumed to be the same. Furthermore, the simulation assumed that the buses stop at all signals, an assumption that the authors noted would lead to an underestimation of the benefits of ITS, since signal priority would eliminate stops and the associated accelerations that generate higher emissions. Their surveys and field measurements revealed a ridership increase on both lines under study, and further suggested that both improved service from signal priority and the passenger information system play a role in improving ridership. Yet, there was no attempt to estimate the emissions reductions, even in a back-of-the-envelop calculation, from possible modal shifts to public transit. For example, there is no indication of whether the new riders might have come from other transit routes, or from private automobiles.

This reveals an important limitation in most studies of the air quality impacts of APTS. There is currently no feedback loop to the travel demand models (see Figure 2-1). Yet, TSP and other operational and level-of-service improvements could increase transit ridership and thus affect mode share. Increasing bus ridership through TSP strategies could lead to a virtuous circle, since a mode shift from autos to buses could provide some congestion relief along the corridor, and the impacts on general traffic from giving priority to transit (which are higher under higher levels of congestion) would be reduced. Changes in ridership from TSP have not been well documented in the US. In Saporro City, Japan, implementation of TSP lead to a 6% reduction in travel time, an impressive 10% increase in ridership (Baker, Collura et al. 2002, p 9). Quantitative measures of bus service levels (travel time, reliability) and qualitative measures of passenger satisfaction indicate that there could be an important ridership effect in the US as well.

The difficulties in assessing the emissions and air quality impacts of ITS transit applications reflect the larger issue of how to incorporate the effects of transit ITS in the standard transportation modeling process. For example, “improved service reliability (resulting in reduced variability of both wait and travel time), and improved ‘quality’ of wait time resulting from real-time traveler information” can both have significant impacts on traveler behavior and thus ridership levels (U.S. Department of Transportation 2005). However, modeling and measuring these effects is not within the capabilities of current demand models.

2.2.6 Summary of Reported Benefits

There has been a growing interest and base of knowledge in assessing the air quality impacts of ITS deployments. Indeed, progress is being made on incorporating ITS-based improvements into transportation network modeling, and linking that output to emissions models through more

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29 However, it should also be noted that with growth in overall travel demand, absolute transit ridership must grow simply to avoid losing mode share.
refined emissions factors. Although many fundamental questions still remain unresolved, some preliminary observations can be made.

Improved traffic flows from ITS seems to provide modest reductions in HC and CO, although NOx emissions are generally more difficult to reduce, as increased flow speeds disproportionately raise NOx emissions factors after about 30-40 mph (see Figure 2-3 and Figure 2-4), and NOx idling emissions are low (meaning that reducing idling is less effective for NOx reductions than for HC and CO reductions). The traffic smoothing aspect of ITS is important, and reductions in hard or sustained accelerations offer the potential to reduce emissions. However, since NOx is not as significantly affected by the power enrichment that occurs during hard accelerations (HC and CO are more strongly affected), reducing these acceleration will do less in the way of NOx. While ETC may reduce hard accelerations events, ramp metering may actually introduce additional hard accelerations, as vehicles quickly accelerate from zero to freeway speeds. Therefore, ramp metering seems to be a better NOx strategy than for HC or CO, although if average freeway speeds are increased substantially, NOx emissions may begin to rise again. Therefore, different strategies may present tradeoffs between NOx reductions and CO and HC reductions.

The quality of studies for advanced traffic signalization is highly variable. There seems to be some potential for emissions reductions by smoothing traffic flows. Indeed, benefits from smoothing traffic flow may be underestimated where average speeds are used, because these studies are not capturing the changes in accelerations and idling. However, there may also an overestimation of the benefits because the question of induced demand has not been adequately addressed.\(^{30}\)

Air quality studies of ITS improvements to public transportation have been relatively narrow in scope, focusing on changes in the bus operations along a particular route, and changes in emissions that result from fewer stops or increased speeds. Some work has been done to assess to what extent different types of signal priority to transit affect regular traffic, with inconclusive results. Impacts on side traffic depend more upon the type of priority given to transit, i.e. whether conditional or not.\(^{31}\) However, the emissions outcomes from more systemic changes to the transportation system, such as mode shift due to both improved service quality and image of the transit system, have not been explored.

Finally, the role of advanced traveler information seems to indicate a balancing act between the congested route and the non-congested alternative, in the case of information regarding incidents. Market penetration, compliance rates, and the severity of the accident determine whether ATIS can distribute traffic flows efficiently, or lead to overreaction and congestion of alternate (usually arterial) routes. In the case of recurring congestion, ATIS does seem to improve network performance. However, it also opens up the possibility of inducing demand through reduced travel times. Again, as with APTS, the potential for ATIS to change mode share and the

\(^{30}\) This tradeoff will be discussed in much greater depth in Section 3.2.1 on induced travel.

\(^{31}\) "Unconditional" transit priority means that priority is given with greater frequency than conditional priority, meaning that regular traffic flows are "interrupted" more often.
possibilities for induced travel from ATIS have not been seriously examined. There is also a serious gap in the studies regarding the use of multi-modal information, which can provide not only traffic conditions, but also transit information for those that may not be accustomed to using public transit, and information on carpool or vanpooling options that can reduce travel time by allowing access to HOV facilities.

So, we are just beginning to understand the impacts of ITS on emissions for “traditional” ITS deployments such as ATMS, APTS and ATIS, and how they can affect emissions of HC, CO and NOx. Here, we have not reviewed studies focused on the air quality impacts ITS for PM, studies that would look, for example, at the effects of ITS applied to freight transportation and diesel vehicles (see the description of CVO in Table 2-2). However, our review of the general literature on ITS and air quality revealed a scarcity of work in this area, compared to the work focused on ozone precursors (NOx and HC) and carbon monoxide. Finally, we have focused on ITS technologies that are deployed primarily for mobility purposes, thus implicitly considering their air quality impacts to be additional, secondary benefits. There are few studies on the possibilities for ITS technologies that are specifically focused on emissions reductions and energy savings. Therefore, we now turn a discussion to these ITS technologies. However, it should be noted, that for the framework we will develop in Chapter 4, and apply to the case studies in Chapters 5-7, we are focusing primarily on ITS technologies used for both mobility and air quality benefits.
2.3 EXPANDING THE ITS TAXONOMY

Within the six functional areas or "user services" described above (see Table 2-2), there are several applications which could be deployed to improve emissions. In fact, as will be discussed in later chapters, several of these applications have been deployed in metropolitan areas for the purpose of meeting or maintaining national air quality standards. Nevertheless, limiting the view to these existing user services – developed primarily for mobility purposes rather than for addressing air quality or other environmental concerns – fails to take into consideration the many emerging applications that are being designed specifically for management of emissions and energy use. These applications have been deployed primarily, but not entirely, outside of the US. However, the concept has been raised in the US under the label of "emissions testing and mitigation" in the US National ITS Architecture.

2.3.1 Emissions Management

So, the idea of integrating emissions detection with other urban ITS applications is not new. In fact, the National ITS Architecture includes an "Emissions Testing and Mitigation" user service as part of the Travel and Traffic Management user service bundle.

"The Emissions Testing and Mitigation user service uses advanced sensors to monitor and implement strategies to reroute traffic around sensitive air quality areas, or control access to such areas. Other technologies provide identification of vehicles that are emitting levels of pollutants that exceed state, local or regional standards, and provide information to drivers or fleet operators to enable them to take corrective action. The service also provides transportation planning and operating agencies with information that can be used to facilitate implementation and evaluation of various pollution control strategies." 32

Considering this user service from the perspective of the ITS-4 – that is, technologies to sense, communicate (i.e. transmit), process and use information (Sussman 2000) – the enabling technology in emissions testing and mitigation is the ability to "sense" or detect ambient air quality levels or emissions from specific sources. Even some of the “visions” of urban ITS deployments in the 1990s explicitly included an emissions detection capability, as seen in the upper right hand corner of Figure 2-5.

Nevertheless, this user service for practical purposes seems to be little more than a oddity found in the ITS Architecture, as it does not appear in the vast majority of the ITS literature; neither is it found in the taxonomy for the classification of ITS benefits and costs, included in the ITS deployment tracking effort, nor mentioned by ITS America. 33

33 This outcome should not be surprising given the institutional players involved in the development of the National ITS Program, mainly highway and transit groups, and as represented in the USDOT’s Joint Program Office (the FHWA and FTA). See Klein (1996). There is no direct involvement, for example, from the EPA.
2.3.2 Taxonomy for Evaluation

While ITS applications can generally be categorized into the six functional areas discussed earlier, in order to make more detailed distinctions between a wide variety of ITS applications, it
is useful to draw upon the taxonomy created by Mitretek Systems (see Appendix B). This taxonomy was developed in support of the US DOT's database on ITS Benefits and Costs in order better classify and compare information on benefits and costs. Although “Energy and the Environment” is listed as one of the five goal areas of ITS by the US Joint Program Office, one sees that the taxonomy used to classify ITS technologies for analysis of benefits leaves out any technologies related to the user system of “Emissions Testing and Mitigation” discussed above.

At the broad level, this taxonomy is divided into “Intelligent Infrastructure” and “Intelligent Vehicles.” One level down, there are the various subsystems, such as arterial management, commercial vehicle operations, transit management systems, road weather management, and electronic payment systems. Below that are different functions, such as information dissemination, response, surveillance and detection. Finally, the last level contains specific ITS applications. While the full Mitretek taxonomy (for Intelligent Infrastructure) is included in Appendix B as a reference, Figure 2-6 illustrates the basic structure of the taxonomy.

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Some interesting observations can be made by comparing the five goals areas of ITS and the subsystems used in the Mitretek taxonomy for evaluation. Three of the five ITS "goals areas" — mobility, efficiency and productivity — reflect benefits that are largely internal to the transportation system, and its suppliers, operators, and users. Looking at the Mitretek taxonomy, these three goals are supported by nearly all of the applications included. However, looking at the two goal areas of ITS related to broader societal benefits — safety and energy/environment — safety and crash prevention is the only one that appears as a separate subsystem under the Intelligent Infrastructure in the Mitretek taxonomy.\textsuperscript{35}

\textsuperscript{35} The institutional history of the National ITS Program can explain the inclusion of safety as an important subsystem. One could argue that the predominance of safety on the ITS agenda has its roots in the early efforts of HUFSAM (Highway Users Federation for Safety and Mobility) to exercise greater control over the development of the national ITS program and the creation of ITS America. Klein, H. K. (1996). Institutions, Innovation, and Information Infrastructure: The Social Construction of Intelligent Transportation Systems in the U.S., Europe, and Japan. Doctoral Thesis in Technology, Management and Policy/Political Science. Department of Political Science. Cambridge, MA, Massachusetts Institute of Technology: 404 pages. In comparison, there was never an analogous "environmental lobby" in the early years of the National ITS Program.
2.3.3 Incorporating Emissions Management

Clearly, the taxonomy fails to reflect the small but growing number of ITS applications that are more specifically directed toward improvements in air quality, vehicle emissions, and energy consumption. These applications are based, for example, on the identification of high emitters through on-road remote emissions sensing, with response strategies ranging from simply providing feedback to drivers on their vehicle’s emissions levels, to restricting the entry of high-emitting vehicles into specific zones. ITS emissions and energy measures can also include automated speed enforcement to move traffic at speeds characterized by more “desirable” emissions factors, or pricing strategies that incorporate environmental externalities into the price of travel.

In this section, we therefore propose an expanded ITS taxonomy as a step toward better incorporating this goal area, as well as expanding the range of mechanisms by which ITS can affect air quality. This addition would include a new subsystem under the heading of Intelligent Infrastructure (Figure 2-7),\textsuperscript{36} where devices are incorporated into the infrastructure to detect and control vehicle emissions, as well as under the heading of Intelligent Vehicles (Figure 2-8), where these functions would be largely internal to the vehicle.\textsuperscript{37} These are diagrammed and described in detail below, following the Mitretek format of dividing a subsystem, in this case Emissions and Energy, into various functions. These subsystems allow for a more precise classification of emerging environmental ITS applications, while maintaining consistency with the accepted taxonomy for the evaluation of costs and benefits.

\textsuperscript{36} Analogous to the inclusion of “safety and crash prevention” as a stand-alone subsystem of ITS.

\textsuperscript{37} As of the writing of this dissertation, the concept of Vehicle-Infrastructure Integration (VII) was emerging as the state-of-the-art in ITS research and development. Assessing the implications of Intelligent Vehicles and VII is an important track for future research.
Figure 2-7 Intelligent Infrastructure - Emissions and Energy Subsystem

Emissions & Energy
- Monitoring, Surveillance, & Detection
  - On-road Remote Sensing
  - Smog Patrols
  - Traveler Reported
  - Air Quality Monitoring
- Emissions Information Dissemination
  - Variable Message Signs
  - I&M Exemptions
  - I&M Notices
  - I&M Quality Control and Auditing
- Air Quality Information Dissemination
  - Variable Message Signs
  - Highway Advisory Radio
  - Internet/Wireless/Phone
- Zone Management
  - Pricing
  - Emissions-based Restrictions
- Enforcement
  - Speed Enforcement
  - LEZ Enforcement
  - Driving Restriction Enforcement

Figure 2-8 Intelligent Vehicles - Emissions and Energy Subsystem

Emissions & Energy
- On-board Monitoring
  - Fuel Economy
  - CO2 Output
  - Emissions
  - In-vehicle Systems
- Driver Support
  - Intelligent Cruise Control
  - Vehicle Idling/Off
2.3.4 Intelligent Infrastructure

2.3.4.1 Monitoring, Surveillance, & Detection

In the same sense that a traffic management system must be able to sense vehicles flows in order to generate a management strategy, a basic function for an energy and emissions ITS subsystem is the ability to accurately detect emissions from individual vehicles, provide surveillance on emissions characteristics for a sample of the vehicle fleet, and monitor air quality at either specific sites or for the entire urban area. To some extent, the ITS Architecture attempts to incorporate these capabilities in the specifications, noting that the Emissions Testing and Mitigation function should include both wide area pollution monitoring (WAPM) and roadside pollution assessment (RPA) capabilities. However, the focus is only on ozone and its precursors, excluding for example, carbon monoxide, although a roadside pollution assessment capability would presumably be a useful tool to identify CO “hot spots” that are important from a public health and regulatory perspective. Furthermore, the ITS Architecture, in defining the roadside pollution assessment function, lumps together several very distinct technological capabilities, such as the ability to measure ozone precursor emissions as well as ozone concentrations, to detect both moving vehicle emissions and ambient air quality levels, and even to be “capable of reading suitably equipped vehicle’s diagnostic data to determine that vehicle’s operational status” (U.S. Department of Transportation 2005). While these are bundled into one definition, these functions required very different technologies and physical configurations.

We will consider four applications supporting the function of emission and air quality “sensing”: (1) on-road remote sensing, (2) smog patrols, (3) traveler reported, and (4) ambient air quality monitoring. These applications differ according to whether they sense emissions (1-3) or ambient concentrations of pollutants (4), and how that information is collected. Being able to detect emissions is particularly important because of the what is known as the high-emitter problem, where a small percentage of the vehicle fleet has very high emissions when the emissions control technologies are not working properly. As a general rule, the dirtiest ten percent of the vehicle fleet is responsible for half of the entire fleet’s HC and CO emissions. Perhaps more surprisingly, “high emitters are found in all model year vehicles; it is not just the old cars that are high emitters” (Heywood 1998, p 17). Even as vehicle fleets become cleaner on average, a portion of vehicles from all model years will pollute substantially. While traditional inspection and maintenance (I/M) programs are an effective remedy to this problem, they often

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38 Air quality, of course, is not only function of on-road mobile sources, but also stationary point and area sources, and off-road mobile sources.

39 The relevant architecture specifications can be found at www.iteris.com/itsarch/html/user/usr19.htm. Last accessed July 15, 2006. However, this remains largely conceptual, since in the US these systems have not been deployed beyond a few isolated cases.

failure to capture the full picture of in-use emissions. Therefore, we outline several ITS
technologies that can identify and address the high-emitter problem.

- **On-road Remote Sensing**

Probably the most effective application within this category is that of on-road remote emissions
sensing. These technologies can measure, process and archive emissions information in real-time for thousands of vehicles, and provide the basis for a range of response strategies that will be
discussed later. On-road remote emissions sensing measures the amount of certain pollutants
by emitting a light beam through the exhaust gas emitted by a passing vehicle. This beam is then
detected at the other side of the road and analyzed for its levels of CO, HC, NO\textsubscript{X} and CO\textsubscript{2}.

The emissions readings can be used with or without identification of the emitting vehicle.
Identification requires coupling of the remote sensing to a license plate recognition (LPR)
system, and can be used for enforcement purposes, for support of I&M programs, or for
otherwise linking information on vehicle model, age, and other vehicle-specific data than can be
accessed from a vehicle registry database. In Denver, Colorado, the Smart Sign vehicle
emissions information system, which coupled remote sensing with LPR, showed a much higher
rate of successful readings for the remote sensing (94% successful/attempted readings) than for
the LPR system (12% successful readings, with high confidence levels, during operational time)
(Bishop, Stedman et al. 2000). If not used for enforcement purposes, this information can kept
anonymous to avoid any privacy issues, for example, linking emissions to vehicle model and
age, but excluding information that could be linked to the vehicle owner or vehicle registration.

In terms of physical configuration, freeway off-ramps have been used in some deployments
because they provide single lanes with heavy traffic, and can be located to ensure that vehicle’s
arriving to the off-ramp will already have their engines and emission control equipment in “hot
stabilized” mode (therefore not capturing the higher emissions rates from vehicles still in “cold
start” mode) (Bishop, Stedman et al. 2000). The equipment can be either permanent and
unattended by personnel (as in the Smart Sign case) or mobile, for example, using vans to move
the equipment from site to site, but requiring technicians to monitor the stations and adjust the
equipment settings to each site. While these deployment have often been stand alone, they could
also be integrated with other ITS facilities such as ETC-equipped toll plazas or weigh-in-motion
stations for freight vehicles.

- **Smog Patrols**

Another source of information and enforcement for vehicle emissions is the use of “smog patrol”
officers, which can be considered as “on-road” enforcement of Inspection and Maintenance
(I/M) programs. Through visual checks of visible smoke (typically for light duty vehicles), or
roadside tests of exhaust smoke opacity (for heavy duty vehicles), the officers can record vehicle
and driver information, and enforce emissions regulations. While this is a much less automated

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41 The use of LPR in Denver’s Smart Sign program was eventually ended to “completely eliminate potential privacy
Reducing Air Pollution.” Environmental Science and Technology 34(6): 1110-1116.
form of on-road emission sensing, compared to the remote emissions sensing systems described above, it can be more directly linked to enforcement by issuing tickets and fines or escorting vehicles to emissions testing centers. This type of system has been used and expanded in the province of Ontario, Canada, since 1998. In the year 2000, the Smog Patrol inspected about 2,000 light duty and 592 heavy-duty vehicles (Ministry of the Environment 2002, p 17). While the number of vehicles is substantially lower than that possible by remote sensing (over 3 million successful CO measurements and 145,500 high-confidence LPR readings), one can argue that the Smog Patrol compensates by focusing on the very highest emitters, visibly smoking light and heavy duty vehicles. Furthermore, the Smog Patrol couples surveillance with enforcement, a function enabled by collaborating with the province’s law enforcement officials. The potential privacy issues related with the use of LPR may make linking readings to enforcement more problematic, although the LPR in London’s congesting pricing scheme indicates that this barrier is not insurmountable.

- Traveler Reported

Finally, another source of surveillance on vehicle emissions is the use of traveler reported high emitters. While this is borderline for being considered ITS, in the sense that it is not advanced technology, we include traveler reported information in order to be consistent with the Mitretek taxonomy, which incorporates traveler reported information for incident management systems. In this case, a dedicated phone number (hotline) or online reporting form can be used by drivers to report vehicles emitting visible smoke. Similar to the Smog Patrol, this relies on visual observation of exhaust smoke. An example of this system is in operation in New South Wales, Australia, where up to 2,000 vehicles are reported to the Environment Protection Authority each month by the public via phone and internet, in addition to the reports filed by government reporting officers. Although the Smog Patrols will have training in how to identify out-of-compliance vehicle emissions (color and density of smoke, duration of the smoke emissions), the public generally will not. Because anyone can report a vehicle, there is a greater probability of identifying high emitters, although legislation will determine how that information can be used for enforcement purposes. The San Francisco Bay Area also has a reporting system for visible emitters, with a toll free number and internet page for reporting smoking vehicles.

In the US, the effectiveness of this type of system is limited as the number of gross polluters emitting visible smoke decreases to a negligible number, although it can target the highest visible polluters. In other areas, in particular, in developing country cities where both passenger vehicles and heavy duty vehicle fleets still have a relatively high number of gross emitters, this type of system may be an effective measure, although the administrative burden of processing traveler-reported information on high emitters may be substantial.

43 Traveler reported traffic information is also used in many advanced traveler information systems, such as SmarTraveler in Boston, which uses information called-in from drivers in addition to other sources.
• Air Quality Monitoring

While the applications described above provide information on the emissions of individual vehicles or a sample of the vehicle fleet, a third application is the use of air quality monitoring to measure pollutant concentrations at specific sites on the transportation network. Most cities have an existing network of air quality monitoring sites to routinely measure pollutants, their precursors and meteorological conditions, such as wind speed and direction, ambient temperature, and relative humidity. In addition to the urban air monitoring network, more focused measurements can be taken to assess concentrations of pollutants and precursors around important transportation facilities. In Europe, a program was launched in five cities to evaluate the potential for a “near real-time vehicle pollution monitoring system that correlates traffic conditions and the resulting levels of pollution” (Information Society Technologies 2004). There are many difficulties in measuring changes in concentrations of pollution due to changes to the transportation system, given the presence of other stationary and point sources in the vicinity, constantly changing meteorological conditions, and the complex chemistry of pollutant formation, such as for ozone. As part of this program, upwind and downwind measurements were taken along a highway in the Netherlands to measure NO, NO2, and PM10, at distances of 50 and 200 meters, in order to determine the changes in concentrations resulting from traffic speed control (Keuken 2004).

2.3.4.2 Emissions Information Dissemination

Using the information gathered through the applications under the heading of Monitoring, Surveillance and Detection, several response strategies can be devised. This section will describe strategies based on the dissemination of information on the emissions of individual vehicles or a sample of the vehicle fleet.

• Variable Message Signs

Bishop and Stedman (2000) describe a vehicle emissions information system called Smart Sign, that integrates highway variable message signs (VMS), on-road vehicle emissions sensing and LPR. The purpose of this system is to provide drivers with immediate feedback regarding their emissions status, in order to encourage drivers to take corrective actions for high-emitting vehicles. Usually the feedback is qualitative, in the case of Smart Sign, indicating that the vehicle’s “health” is good, fair, or poor, and that the vehicle is therefore saving or costing their owners’ money (Bishop, Stedman et al. 2000). The use of VMS represents a more passive approach to emissions control, giving drivers information in the hope that they will remedy the problem either to save money, avoid failing future I/M inspections, or out of increased consciousness about their vehicle’s impact on air quality. In follow-up surveys of drivers, 16% of owners of vehicles in the “poor” category indicated that because of the Smart Sign they had already taken actions to address the problem, although this information could not be confirmed. Indeed, as noted by Bishop et al, “the sign is uniquely suited to be used as a tool to increase personal responsibility of drivers” (Bishop, Stedman et al. 2000, p 1115).

• I/M Exemptions and Notices
While the first two applications supporting emissions information dissemination are based on reporting emissions information directly to drivers, the next three applications are based upon linking emissions information to enhance traditional Inspection and Maintenance (I/M) programs. By using information from remote sensing, different forms of "hybrid" emissions testing programs can be developed. The exact form of these program can vary widely, but include a combination of traditional emissions testing centers and on-road emissions sensing to identify "clean" vehicles that can be exempted from testing or "dirty" vehicles that can be notified and called into the centers for additional testing (Booz Allen Hamilton 1996). Although I/M exemptions and notices represent two sides of the same coin, in practice, clean vehicle exemptions or "clean screening" has been deployed relatively little, while high emitter identification has been more widespread. California, Colorado, Missouri, Texas and Arizona have had the most experience in using remote sensing, and have investigated its use for both clean and dirty screening and program evaluation (Klausmeier 2002). Specifically, Arizona has used remote sensing to identify high emitters and require additional inspections, while Colorado and Missouri have used clean screening (National Governors' Association 2000).

- I/M Quality Control and Auditing

Finally, statistical emissions data on the vehicle fleet obtained from on-road remote sensing can be used for quality control, to verify the validity of test center results, audit specific centers, and evaluate the overall I/M program. Some researchers suggest that using remote sensing to evaluate the effectiveness of I/M programs is likely to be more beneficial than either I/M exemptions or notices (Klausmeier 2002).

2.3.4.3 Air Quality Information Dissemination

In addition to dissemination of emissions information, in metropolitan areas with air quality problems, the dissemination of real-time information on air quality levels can be used in support of "episodic controls" or transportation control measures that are implemented when there is a danger of exceeding the national ambient air quality standards. For example, for days when ozone reaches dangerous levels in the San Francisco Bay Area, "Spare the Air Day" strategies are implemented including extra speed enforcement on freeways, posting of "Observe the Speed Limit" on Caltrans variable message signs, encouraging drivers to limit the use of their pre-1981 vehicles, and working with employers to examine telecommuting options for poor air quality days (Bay Area Air Quality Management District 2004, p 39; Metropolitan Transportation Commission 2004, p 49). In the summer and fall of 2004, a program of free travel on the BART system was tested to measure its effectiveness and cost as an episodic control measure. However, public awareness of these measures is often limited. In Germany and the Netherlands, there are moves toward programs to ban certain vehicles from driving on "ozone alarm" days based on their emissions levels (according to the "Euro" classification for vehicle emissions). Again, adequate dissemination of information on pending ozone alarms would be critical to the success and acceptability of the program by the public, and ITS could have an important role.

For episodic control measures that affect traffic management (such as through speed changes) and promote public transportation (such as with free fares), a combination of Variable Message Signs (VMS), Highway Advisory Radio (HAR), and Wireless/Internet/Phone could be used more intensively as a means to notify the public that these controls are in effect, as well as provide information on alternative travel modes. This is done to a limited extent in Tulsa, Oklahoma as well as in the state of Texas, as will be discussed in Chapter 6.

2.3.4.4 Zone Management

Zone management uses real-time information on air quality levels and/or emissions from individual vehicles to dynamically adjust control strategies. These control strategies attempt to limit vehicle emissions either by pricing or outright restricting vehicle activity within specified areas or zones.

- Pricing

While the motivations for implementing pricing strategies, in particular, congestion pricing or value pricing, are more directly linked to congestion mitigation than to possible air quality improvements, there has been an increasing interest in exploring the air quality outcomes. Many observers hold high hopes for the pricing capabilities of ITS to mitigate the potential for increased travel and sprawl from ITS-based efficiency improvements. For example, Jordan and Horan argue that "price signals that convey the true costs of driving ... will enable transportation to serve the multiple economic, social, and environmental goals implied by the sustainable communities paradigm" (Jordan and Horan 1997, p 70). While congestion pricing has been implemented in an increasing number of cities, the connection to air quality has been limited.

Singapore had the earliest pricing scheme, which has evolved substantially over years to incorporate ITS-based technologies (Chin 1996; Beevers and Carslaw 2005). The UK more recently broke the mold in the traditional thinking in Europe and the US that congestion pricing was politically unfeasible when London began charging 5£ per weekday to enter a 22 km² area in central London between 7:00 AM and 6:30 PM (Mahendra 2004).

Various ITS technologies are used to support pricing strategies, and include fixed and mobile cameras, license plate recognition, and payment made possible by telephone, text messaging, Internet, or self-service machines (London). There are exemptions for alternative fuel vehicles, although this is "the only explicitly environmental measure in the [London] scheme” (Hutchinson 2004). This provision has been a controversial aspect of the congestion pricing scheme, since even the cleanest vehicle will add to congestion. Those involved in the London Congestion Pricing scheme assert that above all "this is traffic and congestion management, not an air quality scheme” (Hutchinson 2004), and that while benefits may have been achieved at the local street level, no significant impact on overall air quality could be identified. However, later analyses using detailed traffic data have identified important emissions changes from the

47 Similarly, in the US, there have been conflicting opinions regarding whether to allow cleaner or hybrid vehicles with only one occupant to use HOV lanes. The concerns are that the HOV lane’s benefit in travel time will be lost if the HOV lanes are "slowed down" by additional, albeit clean, vehicles.
congestion charging scheme, reporting NOx reductions inside the zone of 12% and NOx increases of 1.5% on the inner ring road, and PM10 reductions of 11.9% in the zone and PM10 reductions of 1.4% on the inner ring road (Beevers and Carslaw 2005).

In the US, the road pricing discussion has been focused around “facility pricing” on entire freeways or specific lanes rather than on area-wide congestion charging schemes. High occupancy toll (HOT) lanes have been the primary form of facility pricing, in which single occupancy vehicles are allow on high occupancy vehicle (HOV) lanes by paying an electronic toll. HOT lanes are being operated in Texas, Minnesota, and California. Many metropolitan areas have begun to include or consider HOT lanes as transportation control measures included in state air quality improvement plans. Time-based highway congestion charges have been implemented in Lee County, Florida, Toronto, and New York. Although it has not been studied in-depth, the emissions impact of these two types of facility-based congestion pricing may vary substantially. A time-based highway congestion charge could improve emissions by spreading out the peak, and thus smooth traffic flow and reduce emissions from stop-and-go travel conditions. Also, congestion pricing using HOT lanes, could reduce vehicle miles traveled by increasing average occupancy rates.

There are currently no examples of real-time pricing to charge drivers for their emissions contribution, as most pricing schemes are focused on congestion mitigation, not air quality objectives. Congestion charges in London are not based upon real-time congestion conditions, although Singapore has moved in that direction. A pricing scheme for emissions and energy could use information on individual vehicles emissions as well as information on current or predicted air quality levels, to determine an appropriate emissions charge. Yet, setting the correct charge in order to achieve both air quality and congestion goals is a non-trivial task. The objective of pricing has been to “alter driver behavior to reduce congestion,” not improve air quality (Foster 2004). The additional air quality charge would be based upon either air quality levels (for example, whether there is a danger of exceeding air quality standards) or the emissions of individual vehicles, such as hybrids versus older, high-emitters or heavy-duty diesel vehicles. By incorporating an air quality charge (or emissions fee) to a congestion charging scheme, achieving the desired speed and VMT characteristics would be substantially more complex, since road users would perceive both the congestion charge and emissions charge/fee together as part of the generalized cost of travel.

- Emissions-based Restrictions

Although real-time 
pricing of emissions has not yet been implemented, there are moves toward a real-time enforcement of high-emitter restrictions. Under these restrictions, traffic-monitoring stations prevent highly polluting vehicles from entering the restricted zone when pollution levels are expected to exceed air quality norms. In the case of Beijing, an Italian consortium led by Thetis won a contract with the Municipality of Beijing to implement the Intelligent Transport System – Traffic Air Pollution system (ITS-TAP) in preparation for the 2008 Olympic Games. 48

48 See www.ertico.com/en/news_and_events/ertico_newsroom/thetis_wins_its_project_for_beijing.htm. Last accessed January 30, 2006. The transportation management strategies are based upon local air pollution levels in the
The ITS-TAP system's central data center receives data from air monitoring stations and in cases of forecasted high pollution levels, the center can request that the traffic management center authorize traffic restrictions for identified high emitters. The data center can also request that the advanced public transport management system provide extra buses to transport drivers that cannot cross the into emissions zone (Costabile 2004). Evaluations of the full implementation of the system has not yet been completed, although due to the more stringent nature of Beijing’s ITS-TAP one could expect that it is effective in managing air quality levels. Nevertheless, from the viewpoint of mobility, the system is “disruptive” to travelers (Foster 2004). Many drivers may not have access to up-to-date information on air quality to know whether they will be allow to access the emission zone or not. Pricing would allow for more discretion on the part of the driver who would be allowed to choose whether they are willing to pay the emissions charge to enter or not.

2.3.4.5 Enforcement

Although similar to zone management strategies, the applications under “enforcement” involve the use of ITS technologies to simply enforce standing air quality control strategies that do not change in real time as a function of air quality or emissions levels.

- Speed Enforcement

Emissions-based speed enforcement is based upon similar technologies to regular automated speed enforcement, with speed radar and cameras using license plate recognition (LPR) to identify and fine vehicles exceeding the posted limit. However, the system differs in that the goal is not to prevent speeding as such, but to lower emissions by improving the flow of traffic, avoiding the stop-and-go dynamics that can arise from large variations in vehicles speeds and maintaining traffic speeds within a range at which emissions on a gram/km basis are lowest. These systems should ideally be coupled with monitoring of pollutant concentrations, as discussed earlier, in order to ensure that the “correct” speed limits are set.

Emissions-based speed enforcement has not been widely implemented, but has shown to be effective (in terms of both emissions reductions and revenue generation through fines) in a pilot deployment along a stretch of highway in the Netherlands (Keuken 2004). In the US, areas in non-attainment of air quality standards have also begun to look toward speed control and speed reductions as an emissions control measure, although there has not been as much experimentation with ITS-based for automated enforcement of these limits. In the Memphis metropolitan area, the speed limit is being reduced to 55 miles per hour for commercial trucks, while the speed limit for light-duty vehicles is also reduced to 65 miles per hour, to avoid large differences in speeds between truck and autos (Tennessee Department of Transportation 2005). As discussed earlier, San Francisco uses additional freeway speed enforcement as an episodic control measure for high ozone days. The experience in the Netherlands suggests that both

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49 Comment by Sir Christopher Foster during the discussion following his presentation.
automated speed enforcement and air quality monitoring can be effectively coupled with reduced speed limits and still be cost effective through the revenue generated by fines.

- **LEZ Enforcement**

ITS can also support the enforcement of Low Emissions Zones (LEZ). An LEZ is “a defined area that can only be entered by vehicles meeting certain emissions criteria or standards” (Watkins, Allen et al. 2003). Although similar in principle to the emissions-based restrictions described above, using the example of Beijing’s ITS-TAP system, this system falls under the category of enforcement, because there is no use of real-time information on emissions or air quality to effectively “manage” the system.

Different forms of LEZ have been used in Sweden, and studied for possible application in London (Hutchinson 2004). These LEZ schemes in Sweden have operated by restricting heavy duty vehicles, trucks and buses, that do not meet the required emissions standards, from entering “environmental zones” in city centers. These systems serve to improve air quality both through restricting entry of high polluters, and encouraging vehicle turnover and fleet renovation. Although ITS can be used to automate enforcement of standards, it is noteworthy that in Stockholm, Gothenburg and Malmo, where LEZs have been implemented since 1996, the restrictions have been enforced only by police officers using visual inspections, and with no signage for the zone, with an estimated compliance rate of 90% (Watkins, Allen et al. 2003).50

Different levels of automation of enforcement were considered in London LEZ feasibility study. The study concluded that “a manually enforced scheme, targeting heavy vehicles only, would allow the quickest introduction of an LEZ, however, automatic enforcement using cameras would ensure higher compliance and greater revenues....[and] an automatic approach would be needed if the LEZ were extended to include vans” (Watkins, Allen et al. 2003, p 10). It was also noted that higher compliance would translate into increased air quality benefits. While the cost of automated enforcement would be higher, London also has the advantage of being able to build upon the Congestion Charging Scheme infrastructure, using the camera network, license plate recognition, and using electronic toll tags and readers for identification of specially permitted vehicles.

- **Driving Restriction Enforcement**

As the last application under the Intelligent Infrastructure Emissions and Energy subsystem, is ITS-supported driving restriction enforcement. Compared to Low Emissions Zones, which restrict vehicle circulation or entry into specific zones based upon vehicle type, age, and emissions characteristics, general driving restrictions can include up to the entire fleet. These restrictions range from license plate-based driving restrictions, which restrict circulation to vehicles according to the last digits on their license plates (for one or two days a week, and for the entire day or only during peak hours) to Car Free Days, in which no private vehicles are allowed to circulate without special permits, while older vehicles that are retrofitted with emissions control equipment or entirely re-engined, and thus meet emissions standards, circulate with a special permit as identified by a windshield sticker for visual enforcement.

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50 Newer vehicles are allowed to circulate without special permits, while older vehicles that are retrofitted with emissions control equipment or entirely re-engined, and thus meet emissions standards, circulate with a special permit as identified by a windshield sticker for visual enforcement.
allowed to circulate on one designated day once a year. License plate-based driving restrictions used widely in Latin America, and have been put into place both to deal with air quality problems and to mitigate congestion in cities such as Mexico City, Bogotá, Santiago and Sao Paulo (Figueroa 2004; Hidalgo 2004; Vasconcellos 2004). Plate-based restrictions often aim to meet environmental goals by linking vehicle restrictions and exemptions to vehicle age, emissions control equipment and I/M results.

Few of these schemes have ITS-based technologies for enforcement. Nevertheless, enforcement problems and corruption in many vehicle restriction schemes suggest that automated enforcement, such as cameras and LPR, could be highly beneficial for enforcement. Because of the large number of vehicles that are subject to the restrictions, manual, visually-based enforcement with officers means extremely low detection rates. Therefore, as a deterrent to cheating the system, fines are set extremely high compared to other traffic offenses, which opens the door to bribery of police officers by drivers unwilling or unable to pay the official fine.

2.3.5 Intelligent Vehicles

Having examined emissions and energy ITS applications for Intelligent Infrastructure, we will now briefly review possible emissions and energy applications for Intelligent Vehicles. To date, Intelligent Vehicle (IV) technologies have given little weight to environmental concerns. The overarching concerns underlying the development of IV applications have been safety and convenience for drivers. We will look at two IV functions, which represent increasing levels of automation of the management of a vehicle’s energy use and emissions outputs: (1) on-board monitoring and (2) driver support, primarily in the form of adaptive/intelligent cruise control.

2.3.5.1 On-board Monitoring

The first type of Intelligent Vehicle technology applied to the area of emissions and energy, would be an on-board system to measure and report on fuel economy, emissions of criteria pollutants, and CO₂ output. Most technologies for on-board emissions measurements have been used for research purposes in order to improve understanding of the second-by-second emissions of vehicles. Noland et al provide a good review of the development of on-board emission measurement devices (Noland, Ochieng et al. 2004). Currently, the vehicle instrumentation remains both too expensive and insufficiently robust for a broader spectrum of real-world uses. However, real-time on-board emissions and fuel use monitoring, in principal, could be used as feedback to the driver regarding how their driving styles (for example, driver “aggressiveness”) influence both emissions and fuel use. Changes in driver behavior could have an important effect on emissions, since it has been shown that driving styles, even when using the same vehicle on the same route, can lead to significant changes in emissions levels (Holmen and Niemeier 1998; Nam, Gierczak et al. 2003). In particular, aggressive driving with hard accelerations and decelerations, can produce much higher levels of emissions than a smoother driving style.

51 The once-a-year Car Free Days are more of a large scale public awareness event in order to highlight alternative modes to the private automobile than a regular traffic or emissions management strategy.
This real-time information could be accessed both in-vehicle, in the case of an individual driver, or remotely, for a transit or commercial fleet manager, if supported with a communications module.\textsuperscript{52} It could alert the driver not only to the impact of their driving style, but to possible problems with the vehicle’s emission control system.\textsuperscript{53} However, the actual emissions impact depends upon their driver’s propensity to change their driving styles or take the vehicle in for repairs in response to this information. Coupling this to electronic toll collection and other road pricing technologies could also set the stage for the pricing of emissions, at least from the viewpoint of technological feasibility. By linking on-road remote sensing to in-vehicle systems, one could also communicate information from remote sensing equipment (as described in the section on “monitoring, surveillance and detection” under Intelligent Infrastructure) directly to in-vehicle systems, alerting the driver to possible problems with their emissions control systems.

\section*{2.3.5.2 \textit{Driver Support}}

A more active IV system would be a driver-support system also incorporating factors such as emissions levels and fuel consumption. One example would be an adaptive cruise control (ACC) that operated the vehicle in a manner that would improve both fuel economy and/or emissions performance.\textsuperscript{54} This could be done through a combination of targeting an “environmentally-friendly cruising” speed at which fuel economy was highest, and making less intense accelerations. ACC in commercial trucking has already been shown to result in improvements fuel consumption ranging around five percent (Bishop 2005, p 34). These functions could also be supported by technologies such as “idle-off,” which improves fuel efficiency by turning off the engine during longer idling events.\textsuperscript{55}

In addition to the improvement of emissions performance of individual vehicles, many IV technologies for driver support – adaptive cruise control, lane-keeping assistance – can generate a smoother traffic flow. For example, because intelligent/adaptive cruise control vehicles generally make less intense accelerations and decelerations, the “shock wave” effect of upstream vehicles responding to a hard braking vehicle ahead is attenuated. The smoother response of ICC vehicles “filters out traffic disturbances caused by rapid acceleration transients” (Bose and Ioannou 2002). Smoother traffic flow is typically considered a beneficial by-product of having a sufficient number of ACC-equipped vehicles in the fleet. However, Bishop notes that a number of technologies that can cooperate with one another in order to improve overall traffic flow – applications known as Traffic-Assist Systems – have been “proposed, simulated, prototyped, and

\begin{footnotesize}
\textsuperscript{52} For example, a onboard device for monitoring fuel economy and CO\textsubscript{2} output was developed and integrated with GPS and communications modules so that the user can monitor their vehicle’s conditions while driving, or remotely from the home or office. Japan Corporate News Network (2004) “NEC and Two Other Develop Onboard Remote Vehicle Condition Monitoring Device.”

\textsuperscript{53} Currently, General Motor’s OnStar system includes a service called OnStar’s Vehicle Diagnostic (OVD) service, which can send emails to the owner regarding the performance of key vehicle components such as engine/transmission, antilock brakes, airbags, and the OnStar system itself.

\textsuperscript{54} While we include both fuel economy and emissions, from the consumer viewpoint, fuel economy improvements are more desirable as they translate into savings. This is especially true for managers of fleets of vehicles.

\textsuperscript{55} These technologies are supporting technologies for hybrid vehicles, however, they do not necessary make a vehicle a full hybrid. See www.hybridcenter.org, a website maintained by the Union of Concerned Scientists. Last accessed January 22, 2006.
\end{footnotesize}
tested” (Bishop 2005). In effect, these systems intentionally create positive externalities for the traffic flow.

Earlier we discussed emissions-based speed enforcement under the category of Intelligent Infrastructure. With increasing integration between vehicles and infrastructure, an emerging application is External Vehicle Speed Control (EVSC). The EVSC systems under development (primarily in Europe) combine in-vehicle satellite positioning systems with digital road network databases that include speed limits, and are used to “control” the accelerator pedal to “resist” attempts to exceed the legal limit (Bishop 2005, p 33-34). While these early systems would be static – based upon set legal speed limits – they could also be dynamic speed limits in response to traffic volumes, inclement weather, or even forecasted pollution episodes.

While we have identified two possible energy and emissions applications for Intelligent Vehicles, we have not undertaken a thorough review of the IV technologies and their environmental impacts in a similar manner that was done above for Intelligent Infrastructure. However, as automakers continue to develop IV applications for their new vehicle models, this area will be of increasing importance. We will discuss the implications of this for future research in Chapter 9.

2.3.6 “Intelligent Travelers”

Having discussed both Intelligent Vehicles and Intelligent Infrastructure, we will briefly outline some trends pointing to the possibility of a new category of ITS, which we will label “Intelligent Travelers.” Vehicles and infrastructure are not the only components of the transportation system that have both advanced detection and communications equipment. The travelers on the transportation network increasingly carry GPS-equipped mobile phones, which also include access to the Internet, and can communicate voice, text and graphics and images. Furthermore, travelers often make multi-modal trips, meaning that information should be directed to them, not necessarily to their vehicle, as they may move from one vehicle and mode to another in the course of a day or even during a single trip.

The concept of Intelligent Travelers is best illustrated by example. The most basic example would be a navigation service provided on a mobile phone or other handheld unit for a pedestrian in a new city, where GPS provides the person’s exact location, and the system defines the best route for walking to any final destination or to access points for transportation services (public transportation, airport, carsharing sites, taxi stands). This would represent the non-motorized equivalent of in-vehicle navigation. A more complex Intelligent Traveler application could enhance the current practice of carpooling. Travelers equipped with real-time location and

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56 While most new mobile phones sold in the US have GPS chips built-in, most phones only determine location for 911 emergency communications. Nextel is the exception in that it offers user-accessible GPS navigation functions. Wade Roush, “Roamin’ Holiday: GPS phones promise to change the way we think about location,” Technology Review, September 2005, pp 79-80. However, at the writing of this thesis, Sprint and Verizon were just launching similar user location, mapping and navigation services for specific wireless phone models. For the Rand McNally StreetFinder© Wireless service for Sprint/Nextel phones, see www.randmcnally.com/sfw. Last accessed March 20, 2006. Verizon Wireless’ service is the VZ Navigator.
communications technology (such as a GPS-equipped mobile phone) could participate in real-time, or “impromptu” carpooling.\(^{57}\) In addition to their current location (at their home, office, transit station, or park-and-ride lot) the user could input their desired destination, and other characteristics needed to appropriately match them with a driver looking for a carpooler.\(^{58}\) The system could provide the driver with information and directions for locating the carpooler, and alert the carpooler when the vehicle was approaching, also providing them with information on the vehicle model. As a security component, the carpool match could be registered in a database to identify who is riding with whom.\(^ {59}\) Finally, the system could register the successful carpool in its database and permit access to an HOV or HOT lane. It could also authorize free entrance into a congestion pricing zone, or complete an electronic transaction charging the carpooler and/or driver a reduced payment for entering a congestion pricing zone.

Another emerging transportation mode that could shift toward a mix of Intelligent Vehicles and Intelligent Travelers technologies is that of shared-use vehicle systems, or carsharing. Currently, carsharing utilizes a mix of ITS technologies such as: dispatching and reservations systems accessible via the Internet and telephone, smart card technologies for vehicle access, on-board navigation and traveler information, and communications and tracking systems for vehicle location and identification (Barth, Todd et al. 2003). While some of these technologies are linked to the vehicle itself, such as vehicle location and identification, other technologies, such as smart card access, depend upon identification of both the vehicle and the user.\(^ {60}\) In addition, the on-board navigation and traveler information systems could be replaced by handheld units or mobile phone services, rather than on-board systems in the vehicle itself, therefore avoiding the difficulties in becoming familiar with vehicle navigation units that might vary from vehicle to vehicle, or from one carsharing service to another.

While we do not explicitly include an Energy and Emissions ITS subsystem for Intelligent Travelers, we suggest that the emissions impact could be substantial, especially as these types of systems are “scaled-up” to the point where they could have significant impacts on regional VMT. The core environmental benefits of an Intelligent Traveler system would be to reduce the transaction costs of alternative modes of transportation and facilitate intermodal trip-making. By enhancing the convenience of other modes, they can begin to compete more effectively with the single-occupant private automobile, which remains the predominant mode in the US. In Chapters 6 and 7, we review the case study cities and see how they are using ITS for more environmentally-compatible transportation strategies. In Los Angeles, for example, they have developed a category of measures called “Information-based Transportation Strategies” (or

\(^{57}\) Ibid, p 79.

\(^{58}\) For example, many ridesharing services match riders and drivers according to place of employment, smoking preference, whether they prefer a same sex match, and other characteristics.

\(^{59}\) NuRide, an on-line carpool matching service currently provides benefits to carpoolers in the form of gift certificates for every shared ride that is registered. They also provide a type of screening service for the “desirability” of certain drivers and riders, allowing riders to rank each other according to criteria such as their punctuality and driver safety. Perry Bacon, Jr., “Online Dating for Carpoolers,” *Time Magazine*, February 21, 2005, p 53. Also see www.NuRide.com. Last accessed January 25, 2006.

\(^{60}\) In essence, a valid reservation “matches” the vehicle and the user to the specific time-period for when the reservation was made.
IbTS). These IbTS include online rideshare matching, and integrated freeway and transit information, along with more traditional ITS categories. This again highlights the trend toward ITS services that are more traveler-centric, rather than specific to infrastructure, vehicles or individual modes. The sum effect of these Intelligent Traveler technologies would be to improve what we call the “in-vehicle efficiency” of the transportation system, by using vehicles in a more efficient manner than the current pattern of the single-occupancy vehicle. We will discuss the concept of “in-vehicle efficiency” in the next chapter.
2.4 SUMMARY

In this chapter, we have comprehensively reviewed the literature on ITS and air quality benefits for three major subsystems: advanced traveler information systems, advanced transportation management systems, and advanced public transportation systems. We have also defined and characterized new energy and emissions subsystems for ITS technologies capable of purposely measuring, monitoring and reducing mobile source emissions. Finally, we have discussed the trends toward technologies that "manage" not infrastructure or vehicles, but individual travelers. Therefore, we have addressed the first three questions posed at the beginning of this chapter.

- In what ways can ITS have an impact, whether positive or negative, on transportation-related emissions and overall air quality?
- Which ITS applications have been shown to have an important impact on air quality?
- Are there ITS applications specifically oriented toward the goal of improving air quality or generating fuel savings?

This thesis is concerned with not only the impact of existing and commonly used ITS applications, but how cities could actively use ITS capabilities to achieve not only mobility-related policy objectives, but air quality objectives as well. For this reason, we have attempted to identify or describe emerging and future technology applications that could meet these dual objectives. This will allow us to better gauge how cities are applying ITS in possibly innovative ways to address air quality concerns, when we review the case study cities in Chapters 6 and 7.

For the next chapter, we turn to the final question posed at the beginning of this chapter. When deploying multiple ITS services – often along with conventional infrastructure deployment – how can one unravel the overall air quality impacts? As we have seen when reviewing the air quality impacts of ITS technologies, the focus is typically on the individual project level. And while there are many remaining challenges in this area of research, there is also a need to begin to understand the metropolitan, system-level impacts of these deployments. As a step in this direction, we will present a systems framework for assessing the air quality impacts of ITS, and review some of the insights it can provide when applied to this problem.
CHAPTER 3. AIR QUALITY IMPACTS OF ITS: A SYSTEMS APPROACH
3.1 A SYSTEMS FRAMEWORK

Now that we have reviewed the air quality impacts of a range of individual ITS applications, and expanded the ITS taxonomy to include technologies that would form part of an "emissions and energy" ITS subsystem, we will now present a framework for identifying cumulative air quality impacts from multiple ITS deployments.

3.1.1 Identifying Mechanisms for Air Quality Impacts

As can be seen in this review of studies assessing air quality impacts of ITS, they are highly heterogeneous in terms of the ITS technologies, deployment context, and methodology used to assess transportation system changes and emissions outcomes. The review also shows that assessments focus almost exclusively on mechanisms related to network flows of private automobiles – primarily average speed, but increasingly vehicle modal activity (idling, acceleration, deceleration, cruising). Yet, it has been recognized that this is limited by assumptions that (1) travel behavior, (2) distances, (3) vehicle fleets, and (4) mode shares will not change significantly (Mehta, Mahmassani et al. 2001).

Due to the sensitivity of air quality benefits to the conditions of each city and the uncertainty in the current models, rather than focusing on the magnitude of the air quality impacts, we will present a framework for evaluation based upon the mechanisms by which emissions reductions are achieved (Table 3-1). This systems framework is intended provide a preliminary assessment of overall air quality impacts by incorporating variables that are often assumed to be constant – VMT, mode share of public transportation and non-motorized modes, fleet composition – as variables that can be affected through ITS.

Table 3-1 Nine mechanisms of ITS’ air quality impacts

<table>
<thead>
<tr>
<th>Mechanism</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>VMT for Private Auto Fleet (network level)</td>
<td></td>
</tr>
<tr>
<td>Traffic Volume/Throughput (corridor level)</td>
<td></td>
</tr>
<tr>
<td>Traffic Speed</td>
<td></td>
</tr>
<tr>
<td>Traffic Dynamics (idling, cruise, acceleration, deceleration)</td>
<td></td>
</tr>
<tr>
<td>Fleet Composition (number or % of high emitters)</td>
<td></td>
</tr>
<tr>
<td>Mode Share (split between transit, auto, walk/bike)</td>
<td></td>
</tr>
<tr>
<td>VMT for Transit Fleet</td>
<td></td>
</tr>
<tr>
<td>Transit Driving Cycle (speed, idling (dwell), acceleration, deceleration)</td>
<td></td>
</tr>
<tr>
<td>Transit Fleet Operations (occupancy, # of vehicles)</td>
<td></td>
</tr>
</tbody>
</table>

Before describing each of the mechanisms (or changeable variables) shown in Table 3-1, we emphasize that the focus is on passenger surface transportation systems, although the framework could be extended to incorporate freight transportation. For this reason, with the exception of passenger buses, heavy duty vehicles are not included. In addition, a variable that should be included in future research is changes in the number of trips, in order to capture the higher
emissions produced with cold-starts. That said, we now review the nine ITS-air quality mechanisms.

- **Vehicle Miles Traveled (VMT) for Private Vehicle Fleet** directly affects air quality, since more travel means more emissions. ITS can influence private vehicle VMT in several ways: shorter trip lengths and better trip chaining through route guidance systems or ATIS, avoidance of non-essential trips when advised of poor traffic conditions or incidents through ATIS and incident management systems, or increases in trip making due to induced demand from traffic system improvements.

- **Traffic Volume/Throughput** is also related to overall VKT, but can be used as a measure on a specific route or corridor that might be a “hot-spot” for high emissions/concentrations of pollutants such as carbon monoxide. Changes in traffic volume can reflect trips diverted from one route to another, switching between modes, or additional trip making.

- **Traffic Speed** is an important determinant of emissions on a per kilometer basis. As shown in the previous chapter, emissions rates vary non-linearly, often in a U-shape, with speed. Therefore, traffic moving either very slowly, or very rapidly, will have the highest emissions rates. Traffic speed is also related to traffic volumes or flows, although the relationship is also non-linear, as seen in Figure 3-1.

\[\text{Figure 3-1 Relationship between traffic speed (v) versus flow/volume (q)}\]

\[\text{\begin{align*}
\text{\textbullet \ freely \ flowing \ traffic} \\
\text{\textbullet \ congested \ (stop \ and \ start) \ flow \ conditions}
\end{align*}}\]

\text{Source: Based on (Daganzo 1997, p 82)}

- **Traffic Dynamics** captures the different operating modes of the traffic flow – cruising, idling, accelerating, and decelerating – since average traffic speeds on a link or network can either over or underestimate emissions changes from ITS.

- **Fleet Composition** represents the distribution of vehicle types, size, and emission control equipment and its performance. For example, fleet composition could include the percentage of high emitters or gasoline-electric hybrids in the private vehicle fleet.

- **Mode Share** indicates to what extent ITS, and in particular, Advanced Public Transportation Systems (APTS), can bring about a mode shift from low/single occupancy vehicles to high occupancy vehicles or to non-motorized transportation (NMT) (walking or bicycles), thereby reducing private vehicle VMT and thus emissions on a per traveler basis.
- **VMT for Transit Fleet** represents the sum of all network travel by transit vehicles, similar to private vehicle VMT. However, it should be noted that compared to VMT for private vehicles, vehicle miles traveled for transit vehicles is less tightly coupled to passenger miles traveled, because of the range of occupancy levels for transit vehicles.

- **Transit Driving Cycle** reflects the cruise speed, idling and accelerations/decelerations similar to the mechanisms for general traffic flows, which determine vehicle emissions rates. An important component of this mechanisms is that it also captures vehicle dwell times while passengers enter and exit transit vehicles. It is listed as a separate concept from general traffic speed and traffic dynamics, since transit vehicles may be allowed signal priority or operate along separated guideways.

- **Transit Fleet Operations** can include some of the above operational changes, such as dwell time, but also includes occupancy, route structure, improved headway control, or the ability to use fewer vehicles, and thus minimize transit vehicle miles traveled (VMT), while maintaining the same or better level of service and passenger miles traveled (PMT).

While there is some overlap – and clearly a strong interdependence – among many of these concepts, this list encompasses a comprehensive set of mechanisms, using a manageable number of variables, that allow us to better ascertain how multiple ITS deployments may lead to changes in emissions and thus, air quality.

### 3.1.2 Putting the Mechanisms into a Systems Framework

Having developed a set of mechanisms to classify emissions and air quality impacts, they can be integrated within a qualitative systems framework, to identify interactions between ITS applications (e.g., traffic information and incident management, advanced signal control, transit signal priority), as well as interactions between mechanisms that influence emissions and air quality. The framework is deliberately qualitative for various reasons. First, an early focus on quantification may exclude analysts from thinking about important variables that are not easily measured or modeled, such as customer perception of public transit or induced travel from travel time improvements. Second, this framework is intended to be highly inclusive, so that planners, operators, and other decision-makers can use this framework in the early stages of ITS evaluation, in order to explore various combinations of ITS applications and identify opportunities for emissions reductions or synergies between applications. The framework can be used to identify interesting interactions to be further analyzed quantitatively, with detailed modeling or measurements. In this manner, this framework is complementary to efforts to integrate transportation demand, network simulation and emissions models, by identifying possible areas of interest for future modeling work and/or field measurements.

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61 This approach reflects other research efforts that are underway developing processes for analyzing complex systems. These process, such as the CLIOS process, uses a combination of qualitative and quantitative analysis. The assertion is that quantification at too early a stage of analysis may exclude many of the important social, political, organization and institutional dynamics. Dodder, R. S., J. B. McConnell, et al. (2006). The "CLIOS Process": a user's guide. Cambridge, MA, Unpublished working paper. Engineering Systems Division, Massachusetts Institute of Technology.
3.1.2.1 Layered Systems Diagrams

The systems framework consists of organizing ITS applications into a series of layered influence diagrams. The diagrams should contain the ITS applications (shown in bold in Figure 3-2), the mechanisms for emissions reductions (shown in italics), and other relevant variables. Diagramming is a manner of decomposing, from the top-down, a variety of ITS applications of interest, while focusing systematically on the mechanisms leading to emissions changes. As the number and complexity of the systems grows, the diagrams can be “layered” according to ITS subsystems (in this case, ATMS, APTS, Electronic Fare Payment, and Emissions and Energy). Figure 3-2 shows four different but overlapping ITS applications and their interactions: (1) traffic signal coordination, (2) transit signal priority and AVL, (3) contact-less smart cards, and (4) emissions information variable message signs.

Figure 3-2 ITS applications and air quality mechanisms

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While the diagram indicates the direction of influence through arrows, these arrows do not show magnitude or whether the influence is positive or negative. While there are some well-established relationships that are relatively consistent, other relationships depend on the specific context. For example, transit signal priority can have either positive, negative or neutral impacts on the speed and dynamics of general vehicle traffic. It will also depend on the pollutant, since speeds, accelerations and idling affect NOx, CO and HC differently. The studies reviewed in the previous chapter can be serve as a basis to characterize many of the links; and links that are highly uncertain can be targeted for further modeling or measurement.

3.1.2.2 Key System Interactions

This framework intends to enable transportation analysts and planners to map out and better understand the interactions between multiple ITS deployments and their possible impacts on air quality. The nine ITS-air quality mechanisms are key for tracking how these systems can interact to improve air quality or not, and to avoid focusing too narrowly on only a few of the parameters that affect emissions. For example, while traffic speed is a key parameter in emissions, it is also important to think systematically about whether travel time improvements from increased speeds will induce additional demand, and how those increases in volume and VMT will affect overall emissions.

This focus on key system interactions can help avoid unforeseen outcomes in actual deployments and guide more comprehensive evaluations in ITS. Emissions changes from transit signal priority provides an interesting example. While some analyses only focus on the queuing times for buses at traffic signals (Lehtonen and Kulmala 2002), other studies include the effects on all vehicle traffic (Dion, Rakha et al. 2002). However, most studies fail to include changes in transit ridership/mode share and the subsequent impact on emissions. This framework allows one to highlight frequently omitted interactions. Although it may not be feasible to model or measure these interactions empirically, with this systems framework their potential impacts can be tracked.

Finally, a systems framework can highlight the interactions between various modes, and how several variables can influence mode share. Figure 3-2 shows how ITS deployments – ATMS and APTS – can work in opposite directions on mode share. From one direction, signal coordination can reduce the travel time for trips made in private autos, thus favoring this mode. From the other direction, transit signal priority can increase the reliability and decrease the travel time of trips in public transportation, favoring the use of public transportation. Additionally, smart card technology can improve the image or customer perception of public transportation as a high-quality service, again favoring the use of public transportation. More detailed demand modeling would be required to assess the relative impact of those concurrent deployments on

overall mode share. Yet, this framework can highlight possible conflicts between multiple deployments and overarching policy goals, such as increasing the use of public transportation.

### 3.1.3 Using the Systems Framework

We have described the process for developing the system diagrams in order to understand the interactions between multiple deployments and the ultimate impact on emissions, from both the private vehicle and public transportation fleets. While developing the diagram is part of the learning process and gaining insight into the interconnections between systems, another question is “what to do” with the diagram once it has been developed. We will now describe a simple process for using this approach to structure analyses, as well as make an argument for more extensive use of ex-post analyses of the actual impacts of ITS on air quality.

Applying the systems framework – once the relationships have been diagrammed, as in Figure 3-2 – requires tracing the links influencing the air quality mechanisms. We will take as an example one of the least studied aspects of the effect of ITS on air quality – i.e. mode share. Starting with the air quality mechanism of interest, mode share, by tracing backward, the four factors directly affecting mode share are travel time in private vehicles, and travel time, reliability and customer perception of public transit. Tracing back further, these factors can be influenced by ITS applications such as signal coordination, transit signal priority, AVL, and smart cards. We also find several indirect influences of interest. First, signal coordination for general traffic flow can also impact the travel time of public transit vehicles. Second, contactless smart cards can also reduce average boarding time per passenger, and thus reduce the total dwell time at each stop. If this effect is significant, it can reduce the total travel time for travelers using public transit.

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63 In fact, a “passive” form of transit signal priority is to retime and coordinate signals along transit corridors that better reflect the average speed of transit vehicles, taking into accounts stops and dwell times.
Therefore, we have reduced the more complex Figure 3-2 to the more "manageable" Figure 3-3. These can then be summarized as in Table 3-2.

**Table 3-2 Tabulating the links from ITS to air quality mechanisms**

<table>
<thead>
<tr>
<th>(A) air quality mechanism</th>
<th>(B) influenced by...</th>
<th>(C) ITS applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>mode share</td>
<td>travel time (transit)</td>
<td>transit signal priority</td>
</tr>
<tr>
<td></td>
<td>reliability (transit)</td>
<td>transit signal priority</td>
</tr>
<tr>
<td></td>
<td>customer perception (transit)</td>
<td>smart card</td>
</tr>
<tr>
<td></td>
<td>travel time (private vehicle)</td>
<td>signal coordination</td>
</tr>
</tbody>
</table>

Essentially, if one were studying how mode share could be influenced by the concurrent deployment of transit signal priority, AVL, smart cards, and signal coordination along a corridor, the analysis would require assessing the impact of changes in the relative level-of-service for transit (travel time, reliability, customer perception, etc), and for private vehicles (travel time) on demand for each mode. This requires modeling the impact of the factors in Column B on Column A. The next step in the analysis would be to model or measure the impact of the ITS applications on these four variables: transit travel time, reliability and customer perception, and travel time in private auto. This is modeling the effect of the factors in Column C on Column B.

Tabulating the links between variables also points us to the appropriate analytical tools that can be used to estimate future impacts or measure the actual outcomes.\(^{64}\) The benefit of this

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\(^{64}\) In this sense, the problem structure defines the analytical tools that should be used, rather than the analytical tools defining the structure of the problem.
approach is that it can be used to structure analysis at various levels of sophistication. In the context of a research university, this could be used to structure a combination of detailed travel demand modeling (to go from Column B to Column A in Table 3-2) and modeling of both transit fleet operations and traffic flow (from Column C to Column B). Alternatively, in a metropolitan area where the government agency staff resources and time are limited, this could even be used to structure a simple sketch analysis, which could be then followed with actual empirical measurements of outcomes after the deployment is undertaken.

This brings us to the question of *ex ante* modeling and *ex post* analysis. There is a general bias toward *ex ante* modeling to assess the air quality benefits of ITS. There are important organizational reasons for the trend toward *ex ante* as opposed to *ex post* analysis. First, for transportation agencies implementing ITS projects that may have air quality benefits, it is often a project requirement to develop a quantitative estimate of the expected air quality benefits (for example, to be eligible for funding under the Congestion Mitigation and Air Quality program) (Farrell, Harrington et al. 1998). Second, research universities and institutions are often more interested in advancing the generalizable modeling tools and methods for “predicting” the emissions outcomes of types of ITS applications. There is less emphasis on actually measuring the outcomes of particular “real-world” ITS projects taking into account the full local context. Yet, many of the relationships still cannot be “modeled” or estimated in a satisfactory way. For example, how much can a smart card improve the image and convenience of a public transportation system, and thus increase its ridership? Or, can a smart card only make a difference when deployed in conjunction with other transit service and operational improvements, such as AVL and transit signal priority? While it is not yet feasible to model all of these relationships, a well-structured *ex post* analysis – using survey data, interviews of riders, comparison with other similar transit routes that did not receive the same deployment of ITS services – could be used for more effective evaluation of ITS treatments.
3.2 REASSESSING AIR QUALITY BENEFITS

Following the systems framework, we will reassess the potential air quality impacts of ITS. We will focus on the implications of two issues that are critical to the long-term impact of ITS on air quality and the environment: induced travel and system efficiency. We will then discussed some of the research needs for assessing the air quality outcomes of ITS and other operational improvements, and finally, discuss how emissions and air quality factors can be worked into the deployment and assessment process.

3.2.1 Induced Travel

According to Miller, "the most debated [air quality] impacts will result from induced VMT" (Miller 1999). While the immediate traffic smoothing impacts of ITS generally lead to vehicle driving profiles that have lower emissions rates (the upper portion of Figure 3-4, extracted from Figure 3-2), the long-term impacts of changes in travel volume in response to improved traffic conditions and reduced travel times (the bottom-right portion of Figure 3-4) may be less favorable. Determining the long-term mobility and air quality impacts of widespread ITS deployment depends critically on the question of induced travel from reduced travel time.

Figure 3-4 Traffic flow improvements and induced demand

Induced demand in the context of traditional capacity expansions and additions (such as widening of an existing roadway) has been "reluctantly accepted" by the transportation profession (Dowling, Ireson et al. 2005, p 5). However, it has not yet fully integrated in the transportation planning and project evaluation process. Induced demand generally has a negative connotation because of its relevance to issues of urban sprawl, deterioration of air quality, noise, and other impacts. Yet, it should also be noted that there are economic benefits from induced demand. For example, increased VMT through new trips or longer trips can reflect people being able to access goods, services and jobs or undertake activities that they could not previously reach. Although perhaps not optimal from the “social” perspective, creating additional capacity, and the induced travel that results, may reflect substantial individual benefits by accessing larger or cheaper homes, shop at preferred locations, or access better jobs.
Induced demand, in economic terms, represents the shift in the supply curve that results when the creation of additional road capacity (supply) reduces the cost of travel time. Basic microeconomic theory dictates that this shift in supply will lead to a new point of equilibrium between supply and demand – higher demand for travel (Q2) at a lower price (P2) (i.e. travel time cost) – assuming that the demand curve remains the same (see Figure 3-5). As stated by Noland and Lem, "when any good (in this case travel) is reduced in cost, the quantity demand of that good increases" (Noland and Lem 2002, p 2).

**Figure 3-5 Induced travel under constant demand**

![Graph showing induced travel under constant demand](image)

*Source: (Noland and Lem 2002)*

Yet, in practice, the demand curve rarely remains the same, since changes in population, income and other factors are also at work at the same time. Therefore, the challenge in measuring the

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65 While the supply and demand diagrams are shown here as perfectly linear for simplicity in illustrating the concept of induced travel, both the supply and demand curve are generally curved functions.
extent of induced travel is to differentiate between: (a) the effects of behavioral reactions to changes in supply (a shift along the demand curve as seen in Figure 3-5), and (b) the effects of exogenous factors that also shift the entire demand curve (as seen Figure 3-6).

While most studies have focused on physical road capacity expansion and their effect on total vehicle miles traveled (Cervero and Hansen 2002; Noland and Lem 2002), there have been few studies of the effects of operational changes that increase effective capacity (Stathopoulos and Noland 2003; Dowling, Ireson et al. 2005). Travel patterns change in complex ways in response to changes in the physical capacity and the operation of the transportation system. Travelers search out the best routes, times of day, and modes for travel, and may decide to make additional trips, longer trips or even forgo trips. Travelers may also may more complex changes to their travel patterns by combining trips through trip-chaining, which could lead to a change in the number of trips, route of travel, and perhaps even destinations of travel, as new destinations that are “on the way” are chosen. Noland and Lem also highlight longer-term changes in automobile ownership and land use patterns that can permanently create more VMT (Noland and Lem 2002). We summarize these factors and their potential to increase VMT in Table 3-3.

Table 3-3 Behavioral changes and increased VMT

<table>
<thead>
<tr>
<th>Behavioral Changes</th>
<th>Increased VMT?</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Short-run Impacts</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Change time-of-day of travel</td>
<td>No</td>
<td>Can lead to changes in amount of travel</td>
</tr>
<tr>
<td>Change route of travel</td>
<td>Possibly</td>
<td>Increased VMT if changes are to longer routes</td>
</tr>
<tr>
<td><strong>Medium-run Impacts</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Change destination of travel</td>
<td>Possibly</td>
<td>Increased VMT if destinations are most distant</td>
</tr>
<tr>
<td>Change mode of travel</td>
<td>Yes</td>
<td>Switch from public transit to private auto</td>
</tr>
<tr>
<td>Change amount of travel</td>
<td>Yes</td>
<td>Increase in total number of trips</td>
</tr>
<tr>
<td><strong>Long-run Impacts</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Change spatial allocation of activities</td>
<td>Yes</td>
<td>Repeated origins (home) and destinations (jobs, malls) are more spread out</td>
</tr>
<tr>
<td>Change in auto ownership levels</td>
<td>Yes</td>
<td>Can lead to permanent change in mode and amount of travel</td>
</tr>
</tbody>
</table>

The definition of which changes in travel behavior actually qualify as “induced travel” or “induced demand” remains a source of debate among researchers, since many of the behavioral changes resulting from traffic improvements can be classified as “diverted demand” or changes in travel behavior that can affect flows on a particular facility, without actually increasing the overall level of travel demand. According to Cervero and Hansen, induced travel is a more inclusive term, “reflecting all changes in trip-making that are unleashed by a road improvement” (the first five behavioral changes in Table 3-3), while induced demand only includes new trips, longer trips, and mode shifts (Cervero and Hansen 2002). Dowling et al (2005) contend that only changes in the amount of travel (i.e. changes in the number of trips made) actually represent a change in the level of demand, while the rest of the possible behavioral changes represent diverted trips. They further argue that VMT is “not a particularly good measure” of the demand for travel (Dowling, Ireson et al. 2005, p 8), because it captures many behavioral changes that are
not necessarily indicative of an increase in demand. From the viewpoint of air quality, another
critique of Dowling et al is that using VMT as a measure of induced demand leaves out
important time-of-day shifts that can be important for emissions and air quality. Dowling et al
also raise the issue of whether only new trips should represent induced travel, or longer
trips as well (Noland and Lem 2002). However, they define induced travel simply as “the
increase in VMT attributable to any transportation infrastructure project that increases capacity”
(2002, p 4). In more recent works by Noland, he expands this definition to say that “induced
travel effects will occur from any network change that reduces travel times, including those
aimed at traffic flow improvements” (Noland and Quddus 2006). This is an important shift in
the definition from the perspective of ITS, since it does not only focus on physical infrastructure
projects, but can also incorporate operational projects.

While debate remains, there seems to be growing convergence around the definition of induced
travel as an increase in daily vehicle miles traveled (VMT) for a specific geographic area
(DeCorla-Souza and Cohen 1998). This definition reflects in large part the influence of
environmental interests on the debate surrounding induced demand. Indeed, according to
Dowling, “following a landmark court case in the San Francisco Bay Area, the existence of
induced demand for travel has been recognized and must be dealt with in planning transportation
facilities” (Dowling, Ireson et al. 2005, p 6). Similarly, Noland and Lem cite the follow rationale
for their definition of induced demand: “We define induced travel to be an increase in VMT, since VMT growth is one of the primary sources of increased environmental and social costs as well and representing the potential benefits of increased mobility” (Noland and Lem 2002, p 4).
DeCorla-Souza and Cohen follow a similar logic, noting that: “The debate about induced travel in metropolitan areas has arisen primarily because of the presumed negative environmental impacts of increased vehicle use.... Thus, it is clear that what is of concern to environmental groups is additional daily vehicle miles of travel” (DeCorla-Souza and Cohen 1998). Yet, as illustrated by the discussion above, VMT as a measure of induced travel does not capture all phenomena of interest for air quality, such as time-of-day shifts and increases in the number of trips, and therefore the number of cold starts.

From the viewpoint of the individual traveler, induced travel can result from both in short-run
changes in route, destination, etc. and long-run decisions about locations of homes, jobs and
other regular destinations, as well as decisions regarding the number of automobiles per
household, decisions which then further influence travel patterns. In terms of short-run

66 Dowling et al suggest that time-of-day shifts are important because shifts between peak and off-peak can have important impacts on speeds, and therefore on emissions. Dowling, R., R. Ireson, et al. (2005). Predicting Air Quality Effects of Traffic-Flow Improvements. National Cooperative Highway Research Program (NCHRP) Report 535. Washington, DC, Transportation Research Board. However, from the viewpoint of the atmospheric chemistry of ozone formation, the time-of-day of emissions may also be important. Emissions of ozone precursors, VOC and NOx, may have different impacts on ozone concentrations depending upon when and even where those emissions occur. This is due to the variability of atmospheric conditions (wind direction and speed, sunlight, precipitation, etc.) and the evolution of the chemistry over the course of a day (due to photochemical aging, limited pollutant lifetimes, etc). For a review of the complexity and uncertainties related to the relationships of ozone to its precursor pollutants – VOC and NOx – see Stillman, S. (1999). “The relation between ozone, NOx and hydrocarbons in urban and polluted rural environments.” Atmospheric Environment, 33(12): 1821-1845.
behavioral changes, one can identify the three factors articulated in Down’s classic theory of triple convergence. According to Downs (1992), an increase in capacity of an expressway or freeway leads to three types of convergence: (1) spatial convergence, where drivers switch to the improved facility from alternative routes, (2) time convergence, where drivers formerly traveling at just off-peak hours return to the peak, and (3) mode convergence, where public transit users who have the option to use a car, decide to drive on the now faster route (Downs 1992).

These three factors are often the source of disagreement about what should be considered as induced travel and not. For example, changes in the time-of-day of travel – drivers switching to their preferred travel time (most likely the peak hour) – do not represent induced travel, since the daily VMT does not change. However, the improved traffic conditions during the off-peak hours can lead to an increase in discretionary trips during the off-peak, thus increasing the total amount of daily travel (Noland and Lem 2002). Changes in routes will likely lead to changes in VMT, but the question is whether those route will be over longer or shorter distances, and whether net VMT will therefore increase or decrease. Mode changes from public transit to automobiles will unequivocally lead to greater VMT, since a passenger on a bus or metro is now an additional driver on the road. One could debate that this is not induced demand, since no new person trips are involved (DeCorla-Souza and Cohen 1998), adhering to our definition of vehicle miles traveled, the result is clearly induced travel. Changes in destination can reflect both a short-run change, as drivers chose new destinations for shopping or restaurants, or long-run change as changes in the accessibility of different locations lead to changes in job choice. In general, as travel times are reduced, further destinations that were previously inconvenient will now be accessible. Finally, changes in the amount of travel (i.e. new trips) is the most commonly accepted form of induced travel from additional freed-up capacity.

Turning to the longer-run impacts of improvements to capacity or travel time, in addition to changes in destinations, there can be changes in trip origins, basically, where people live. New or expanded transportation infrastructure can either change the accessibility of existing residential developments or open up new areas to new developments, leading to longer trips originating in areas that were once considered to be “too far” from job and other trip destinations. Finally, increased capacity or improved travel time can influence household choices regarding purchasing of a first or second (or more) cars. Owning an automobile will change not only the mode of travel, greatly diminishing the probability that an individual will continue to use public transportation or walk or bike to their destination, but may also have an impact on the amount of travel, leading to additional trips. Therefore, while improvements in travel time and overall levels of service can induce travel in the short-run (a movement along the demand curve, see Figure 3-5), these long-run structural changes can lead to more fundamental changes in travel demand (a shift in the demand curve, see Figure 3-6).

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3.2.1.1 Induced Travel and ITS

The core of the induced travel debate has centered upon expansion of highway capacity, whether in the form of entirely new facilities (on the periphery of urbanized areas) or the addition of lanes to existing, congested facilities. However, the increasing use of alternative strategies to deal with congestion means that the impact of these strategies on induced travel must be considered. In recent years, the Annual Urban Mobility Report developed by the Texas Transportation Institute – probably the definitive source on actual congestion levels in metropolitan areas in the U.S. – has taken an increasing interest in operational improvements and their ability to reduce congestion and delay. The operational treatments analyzed include ramp metering, incident management, signal coordination and access management.

Using the examples of ATMS and ATIS, we will now reconsider what influences the time cost of travel, how it should be measured, and how ITS can lead to induced travel in the absence of changes in physical capacity and possibly even in the absence of changes in travel time. We will explore these questions using the examples of ATMS (for both recurrent and non-recurrent congestion) and ATIS.

- ATMS for Recurrent Congestion

Compared with traditional transportation expansion projects, the capacity increases at the system-level from ITS-based transportation improvements are generally thought to be relatively minor. Nevertheless, some argue that any network change that reduces travel times can induce travel (Noland and Quddus 2006). At least at the facility or corridor level, the capacity increases are often non-trivial. For example, the ramp metering strategy for a section of Interstate-94 in the Twin Cities showed reductions in travel time of 13%-16% compared to the non-ramp metered scenario (Hourdakis and Michalopoulos 2002). Taking the hypothetical case that ramp metering is put into place for a city’s entire freeway network, we will assume a more conservative number of a 10% reduction in travel time. Following DeCorla-Souza and Cohen’s elasticity range of “moderate” demand elasticity (-0.5) to “extreme” elasticity (-1.0), the ramp metering could induce between 5% and 10% additional VMT for the ramp-metered freeway network (DeCorla-Souza and Cohen 1998).

Both for freeway management and arterial management, the results reviewed in the previous chapter seem to indicate that short-run reductions in emissions can be made from improving traffic operations and thus smoothing traffic flows. However, the possible impacts of induced demand from travel time savings in the medium and longer run may overshadow these early improvements, in particular, if changes in land use and the spatial distribution of trips create patterns of longer trip making. Dowling et al (2005) have incorporated induced demand effects into its comprehensive modeling framework for the air quality effects of traffic flow improvements at the network level. However, at the project or facility level, there are few studies assess the tradeoff between smoother traffic (lower grams/mile) and induced travel (more miles) (Stathopoulos and Noland 2003; Noland and Quddus 2006).

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68 Also see www.fhwa.dot.gov/steam/doc.htm for an abridged version of the paper. Last accessed February 1, 2006.
Noland and Quddus took an interesting approach to testing this issue. They first modeled the emissions reductions from improving traffic flow on a congested network, using a microscopic traffic simulation model (VISSIM) coupled to a microscopic modal emissions model (CMEM). The traffic flow improvement involved the addition of a lane on a road merge, which would both increase average speed and reduce acceleration and deceleration events. CMEM provided the emissions reductions from the smoother traffic. Then, instead of attempting to endogenously model the induced travel from the traffic flow improvement, induced travel was exogenously simulated through 1% incremental increases in the number of the vehicles. For each 1% increment, emissions were again modeled, until a "break-even point" was reached where emissions were equal to the initially congested case. They then calculated the demand elasticities associated with the break-even points, and found that these elasticities were "realistic and within the bounds of estimated travel time elasticities in the transport literature" (Noland and Quddus 2006, p 13). A further contribution of this paper is that emissions outcomes were modeled for different vehicle mixes. The comparison across cleaner and more polluting vehicle mixes showed not only that the short-term benefits of flow improvements were "rapidly diminished by induced travel, but that the short-term benefits from cleaner vehicles were even lower, and thus would be easily canceled out by induced trips. While this study provides a good test of the potential for emissions increases from induced travel to cancel out emissions reductions from traffic flow improvement, it is only applied to the case of a very localized project (addition of a lane on a road merge). So, the full network effects of induced travel from traffic flow improvements, are not clear.

- ATMS for non-recurrent congestion

Clearly, there is increasing evidence that reducing travel time can indeed induce additional travel. However, the transportation profession is also beginning to distinguish between travel time and the reliability of travel time. The Texas Transportation Institute, for example, has developed a Buffer Time Index, which can be used to calculate how much additional time must be budgeted to make a trip that is (likely) to be on-time. Shrank and Lomax use an example of a peak-hour commuter in an average congested city. In order to arrive at work on-time for 95% of the days, they calculate that a person would need to plan for 42 minutes of travel every day, even though the average travel time might be 26 minutes (Schrank and Lomax 2005, p 74).

This additional trip planning time is not included in any studies of induced travel to date. In part, this may be because traditional capacity enhancements, the main "culprit" of induced travel, do not affect travel time reliability alone. Yet, many ITS technologies, above all incident management applications, are deployed specifically to address non-recurrent congestion events that degrade travel time reliability. One could reason that increasing the reliability of travel times – and thus reducing the additional “buffer” time that needs to be included in total travel

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69 They use a travel time index (TTI) of 1.3, where a peak trip is 30% longer than an off-peak trip. This would be equivalent to a city such as Austin, Texas or Charlotte, North Carolina. Indeed, the average TTI for all 85 areas surveyed is 1.37. Schrank, D. and T. Lomax (2005). The 2005 Urban Mobility Report. College Station, TX, Texas Transportation Institute.

70 To the extent that travel times are reduced, variability in those travel times are also reduced (see Schrank and Lomax, 2005, Exhibit 37). However, capacity expansions cannot specifically focus on improvements in reliability.
time—could induced additional travel. By reducing the buffer time, more time could be
dedicated to actual travel. This would be consistent with the literature on travel time budgets
first proposed by Zahavi (Zahavi 1979). Most researchers looking at travel time budgets have
found that between 1.25 and 1.5 hours of each day are “spent” on travel (Dowling, Ireson et al.
2005), and that this time share is relatively independent of mode (Schafer 2000). Therefore,
because ITS applications can target non-recurrent congestion and thus improve reliability,
researchers may be forced to reconsider how travel may be induced by travel time reliability
improvements. Indeed, one can argue that the induced travel should be considered for any
improvement to the level of service—travel time, reliability, comfort, etc.

- ATIS and change in travel behavior

Finally, we consider how advanced traveler information systems (ATIS) can change travel
behavior. Following from the discussion on travel time reliability, ATIS can change perceptions
of travel time and reliability. Even if actual travel time reliability does not change, real-time
traffic information could reduce the so-called buffer time needed to ensure that one arrives on
time with reasonable probability. As suggested above, by reducing the buffer time that needs to
be incorporated into travel planning, more time could be dedicated to additional or further travel
(thus increasing VMT and emissions). Also, real-time information on alternate routes could
increase reliability for the individual driver, even though the reliability of the system remains the
same, by giving them various options to arrive on-time. Indeed, as suggested by Kaysi, “ATIS
can act like added capacity in the transportation network in the sense that is can show where
there is ‘available’ capacity in real time” (reference (Kaysi, Chazbek et al. 2004)).

3.2.1.2 ITS versus Physical Capacity Expansion

Although important to consider these impacts, especially as ITS technologies become
increasingly effective, there are still reasons to believe that ITS is not inducing travel to the
extent that physical expansion does. The first argument is conceptual. Investments in physical
transportation infrastructure are “lumpy” (Sussman 2000). Whether adding a new highway,
adding new lanes to an existing highway, adding buses to a route, or a light rail line, the change
in capacity is a step-change in terms of the number of vehicles or passengers that can be served.
In contrast, ITS investments represent a much smoother function for capacity addition. Traffic
signal coordination can range from two intersections to an entire network, in small incremental
steps (see Figure 3-7). In the same manner, traveler information can reach a few or many
drivers, depending upon its level of deployment or market penetration. Therefore, extending this
argument, one can postulate that in the absence of major step-changes in capacity, the induced
travel from ITS-based improvements will be more restrained. Empirically, we have no estimates
of the “steepness” of the curve for ITS-based improvements (three possibilities are shown in
Figure 3-7). In terms of investment for ITS, we are probably still at the far left side of the graph,

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71 It should be noted that this is an average travel time budget per person. Because there would be a distribution of
travel time, there may be individuals at the very low end of the travel time budget, dedicating maybe 20 minutes a
day to travel, and other individuals at the extreme high end of the travel time budget, dedicating two or more hours
daily.
as spending for traditional capital infrastructure is order of magnitude greater than spending on ITS.

Figure 3-7 Physical expansion versus ITS-based improvements

The other argument is empirical. As will be observed in the five case studies, none of the cities presented a case in which ITS-based improvements were used as a true substitute or alternative to capacity expansion. According to interviewees, ITS could serve as a delaying tactic, improving levels of service, for several years in some instances, until physical capacity expansions could be initiated. Therefore, the perception is that ITS, at least in its current form, cannot improve travel times to the extent that traditional capital projects can. Current ITS technologies therefore offer a fraction of the mobility and capacity benefits that traditional infrastructure can, yet also at a fraction of the cost. The question that remains is whether higher levels of investment in ITS (moving to the right in Figure 3-7), or improvements in the effectiveness of ITS (a steeper slope for ITS-based improvements in Figure 3-7), will bring us to the point where ITS-induced travel is as critical of an issue as induced travel from physical capacity expansion.

3.2.2 System Efficiency

The concept of efficiency has been a guiding principal in the field of ITS, the core argument being that ITS can generate a more efficient use of the existing infrastructure. Thus, the focus in the ITS community has been nearly exclusively on what we will call “vehicle-on-infrastructure” efficiency, or how effective capacity (vehicles per unit of time), can be improved. For example, efficiency (as measured by effective capacity or throughput) is one of the measures of effectiveness developed by the Joint Program Office. But, the systems perspective allows us to identify two other types of efficiency that can affect air quality: fuel/emissions efficiency (grams of fuel consumed or emissions emitted per vehicle-mile or vehicle-hour), and passenger-in-vehicle efficiency, what we will call in-vehicle efficiency (passengers per vehicle-mile).

To give a sense of the relative costs, installing a traffic signal can cost on the order 100,000-200,000 dollars, installing a computerized transportation management system along a 10-mile corridor may cost in the range of 5 million dollars, and widening a 5-10 section from a 2-lane to 4-lane divided roadway, can cost tens of millions of dollars. Although these costs vary substantially from one area to another, this gives a sense of the relative scale of costs. For consistency, all example were taken from Houston’s 2006-8 TIP.
Most of the air quality studies have identified air quality impacts due to changes in fuel/emissions efficiency that result from smoother traffic flows. In other words, traffic flows are managed in ways that change the driving patterns of individual vehicles—less idling time, fewer acceleration/deceleration events, speed changes. In addition, we also saw with the Emissions and Energy subsystem that certain applications can change the emissions profile of individual vehicles within the fleet, above all, the high emitters. However, the discussion on induced travel also highlighted how changes in fuel/emissions efficiency (lower g/km) also have to compete with growth in VMT (higher km). Smoothing traffic flows improves vehicle-on-infrastructure efficiency, and thus can attract new or longer trips by reducing travel times.

In-vehicle efficiency clearly reflects the systems perspective, taking the traveler to be the basic component with the transportation system. The most simple example of in-vehicle efficiency is change in mode share, where travelers are switching from travel in single-occupancy vehicles, to public transit, ridesharing via vanpools or carpools, bicycling or walking. The concept of “in-vehicle” efficiency is also reflected in the trend toward HOV and HOT lanes as managed lanes. For example, the FHIWA emphasizes the need to use lane management to preserve the person-movement capacity, as opposed to the vehicle-movement capacity (Federal Highway Administration 2003). Rather than determining how to most efficiently accommodate vehicles on a fixed quantity of infrastructure, this shifts that perspective to consider how to most efficiently accommodate travelers in a fleet of vehicles on a fixed quantity of infrastructure, while possibly allowing fewer vehicles to be used. What matters here is not necessarily how efficiently vehicles are moved, although that may be a part of it, but how efficiently travelers are moved. However, it moves the focus beyond just mode shifting. In-vehicle efficiency can also reflect operating practices of public transit providers. With APTS, the increased control over fleet management can enable operators to service the same passenger level with an equal or improved level or service with fewer vehicles, and thus more passengers per vehicle on average. This concept can also encompasses emerging modes of transportation such as carsharing, in which the many “members” of a carsharing organization make use of a smaller fleet of vehicles, making more efficient (intensive) use of each individual vehicle.

The systems perspective is critical to understanding how to effectively plan for improvements in in-vehicle efficiency. The success of ridesharing programs (carpools, vanpools, or mini-vanpools), carsharing organizations, or the usage of a HOV, all benefit from positive network externalities. For example, for each individual that decides to join a carpooling program, there is not only an internal benefit to them as another travel option or savings on gasoline, but an external benefit to the current and future members of the network, since it increases the possibilities of finding a convenient and suitable carpooling or vanpooling “match.” Similarly, with HOV lanes, the benefits to commuters from HOV lanes increase at a greater rate than the rate of growth of HOV lane miles, because a network of HOV lanes provides much greater benefits than a single HOV lane.

3.2.3 Research Needs

Pulling together the review of the studies on the air quality impacts of ITS (Chapter 2), and the application of our systems framework (this chapter), we can see that there are many
methodological and data issues to be overcome in assessing the emissions outcomes of ITS deployments. There are outstanding issues in terms of both the level of detail (or depth) required to identify air quality impacts, as well as the scope of analysis (or breadth).

In terms of depth, there are several key areas for future research and data gathering to advanced the state of the art in modeling the emissions impacts of ITS for individual modes or specific types of projects. These types of issues represent the bulk of the current research on the emissions impacts of ITS, as reflected in the literature review in Chapter 2. While we identify some important issues, this is not an exhaustive list of the outstanding research questions.

- Better understanding of how ITS changes the vehicle modal activity distribution (i.e. how much time is spent cruising, acceleration/deceleration, or idling) on a second-by-second basis from both field data and simulation modeling.
- Additional field measurements – monitoring individual vehicle emissions under real-life operating conditions – to develop emissions factors for instantaneous speed and acceleration profiles (i.e. grams per second as a function of speed (mph) and acceleration (mph/sec)). These field measurements need to span a wide range of vehicle characteristic to be able to represent alternate vehicle fleets, including for example, high emitters, hybrid vehicles, public transit vehicles, etc.
- Field measurements to monitor actual pollutant concentrations along ITS-modified corridors, for comparison with simulated emissions levels.
- Analysis of the relative impact of public transit ITS applications on transit ridership and overall mode share.

While progress is being made on these issues of “depth,” the breadth of the analyses undertaken is generally weak. One of the key issues highlighted by our systems framework, is the lack of the comprehensiveness of analyses. Dowling et al (2005), which documents the results of the National Cooperative Highway Research Program (NCHRP) Project 25-21, is one of the few initiatives underway to model the system-wide impacts (Dowling, Ireson et al. 2005). While the studies reviewed above have advanced understanding of the localized impacts of single ITS deployments, the system-wide impacts (including all modes) from multiple ITS deployments, are far from clear. Therefore, in terms of the “breadth” of analysis, the following additional issues need to be addressed by researchers.

- Whether the mix of metropolitan ITS deployments – whether more heavily oriented toward transit, traffic, information, etc. – can change the modal split between transit, signal occupancy vehicles, ridesharing, and non-motorized transportation (walking and biking).
- The extent to which traffic flow improvements from ITS lead to induced demand, and the relative size of emissions reductions from changes in vehicle modal activity compared to emissions increases from higher VMT.
Related to the previous point, whether and how ITS applications can be used to improve “in-vehicle efficiency” through Information-based Transportation Strategies (IbTS) through transit and alternative modes such as ridesharing and carsharing.

While we cannot answer these questions fully in this thesis, we have developed a framework which can be used to better evaluate these issues. The system framework indicates that the mix of metropolitan ITS deployments can affect mode share. In Section 3.1.3, our example of the impacts of ITS on mode share indicate that the combination of transit signal priority, AVL and smart cards should favor greater use of transit through improve travel time, reliability and image. Signal prioritization, if negatively affecting general traffic flow, could even provide an even greater advantage to public transit by “degrading” the traffic conditions for travel in private autos. However, the potential benefits of public transit ITS also can be hindered by traffic signal coordination that provides more favorable conditions to travel by private auto (i.e. through the timing of signals along a corridor) rather than by public transit. While we can speak to the direction of influence, the magnitude of influence is uncertain.

Although there is limited work in the area of induced demand and ITS, it is an important area of future work. Noland and Quddus provide an interesting example of how to assess the trade-offs between reduced emissions from improved traffic flow and increased emissions from induced travel. Their results indicate that induced travel can cancel out any initial emissions benefits from improved traffic flow, although the relative tradeoff will be sensitive to how “clean” the vehicle fleet is (Noland and Quddus 2006). We would further argue that because many of aspects of the “level of service”, such as travel time reliability, are not yet being incorporated into the models, there is even more potential for induced travel than what currently is modeled and measured.

Finally, there is little research to date regarding the effects of ITS on improving in-vehicle efficiency. Because the availability of real-time information on non-SOV travel options reduces the transaction cost of using those options, they should, in theory, become more attractive and more widely used. Furthermore, many of these systems provide network effects, so that as the system expands, the benefits increase at an even greater rate than the system’s own expansion. Anecdotally, the increasingly widespread use of on-line rideshare matching, and the evolution of carsharing organizations toward more automated trip reservation and vehicle access and control, provides some evidence that there are at least perceived, if not real, benefits from these technologies.

As compared to the state of the art, described here, the “state of the practice” for measuring the emissions changes from ITS-based improvements to the transportation system will be reviewed more in-depth in Chapters 6 and 7 when we look at five specific cases of cities using ITS for air quality (such as Transportation Control Measures or for CMAQ funding). As a general comment, because the full documentation of the methodology for measuring or modeling used

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73 For example, if transit signal priority is not “conditional” – for example, upon whether the buses are running on time or behind schedule – then priority is granted much more frequently, leading to more frequent “disruptions” of the signal timing and coordination with other signals.
by the agencies or their consultants is not always publicly available or accessible, the accuracy or comprehensiveness of the results cannot always be assessed in detail. We will discuss the state of the practice for assessment of the air quality impacts of ITS in more depth after presenting the case studies.
3.3 A MODEL FOR DEPLOYMENT AND ASSESSMENT

The EPA’s Office of Mobile Sources, in a short report on ITS as Transportation Control Measures,\(^\text{74}\) refers to the “sustainable use of ITS technologies” (U.S. Environmental Protection Agency 1998). According to the EPA, sustainable ITS strategies are those that, for example, can improve traffic flow without inducing additional travel or fostering the number of single occupancy vehicles. In practice, “sustainable use” has proved to be difficult, given that pressures for mobility improvements often trump air quality concerns, and “win-win” strategies are not always perceived to be a win from both sides. Also, because many uncertainties regarding the emissions impacts of ITS have been downplayed, ITS projects have frequently been deployed with the promise of reducing emissions from smoother traffic flow. In many cases, these projects have been funded through programs such as the Congestion Mitigation and Air Quality (CMAQ) program funds, a federal funding category for transportation projects that can provide air quality benefits. Environmentalists have critiqued the use of these funds because of the possibilities for induced travel canceling out the early emissions benefits from smoother traffic flows. Therefore, deploying ITS in a sustainable manner, is more difficult than simply identifying so-called “win-win” technologies.

Because there are few ITS projects that can be said to have unequivocal air quality benefits for all cities, we propose instead a process for beginning to use ITS as a tool for air quality improvements in practice. We base this approach on the systems framework, which shifts the locus of analysis to \textit{ex post} measurements, rather than \textit{ex ante} modeling. There are three approaches to incorporating emissions and energy goals into ITS deployment strategies.

\textit{\textbf{(1) Measuring/modeling emissions impacts of ITS deployments}}

The first approach to addressing the air quality impacts of ITS deployments is to begin to measure or model the emission changes from ITS deployments. This is a passive approach, in which one is simply tracking and possibly reporting emissions changes from ITS deployments. It can involve either back-of-the-envelop calculations using simple equations for changes in speeds, delay times, volumes, and emissions factors based on average speed, or more detailed modeling of both traffic flow and emissions profiles. State or local transportation agencies will often have access to the necessary information to make rough calculations of emissions changes from changes in average travel speeds and emission factors based on average speeds. However, for more complex modeling and/or measurements of emissions changes, these agencies often turn to consultants, contractors or university partners.

While the more simple approaches may mask some of the short-term dynamics (changes in acceleration events) and long-term dynamics (induced travel), it can at least serve as a basis for beginning to understand the changes in emissions that are possible from a given deployment. However, we add the caveat that by not incorporating factors such as induced demand, acceleration events, and mode shifts, back-of-the-envelop calculations may provide misleading

\(^\text{74}\) Transportation Control Measures (TCMs), which reflects more of a legal definition than a technical one, are reviewed more in-depth in Appendix C.
results, in terms of not only the magnitude of the emissions changes, but the possibly even the directionality of emissions changes.

This approach sometimes is taken when cities decide to take credit for ITS deployments in their air quality plans. However, these are often *ex ante* studies that project emissions reductions on future or ongoing ITS deployments, often as a condition for funding those projects. *Ex post* studies that evaluate the actual results of emissions reductions are much less common (Farrell, Harrington et al. 1998). In addition, assessments are generally undertaken on only those ITS technologies that are expected to be able to show emissions reductions. A more complete approach of this type would model and or measure the air quality impacts of all major ITS deployments, not only those that are anticipated to have air quality benefits.

(2) *Maximize possible emissions reductions from existing or planned ITS deployments*

The second approach is more proactive in managing the emissions from ITS deployments. By using information regarding the emissions impacts of ITS deployment, current and future ITS deployments can be more finely tuned to increase their potential for emissions reductions. Operational strategies for traffic signals, ramp metering or transit signal priority can be modified to improve emissions performance. For example, transit signal prioritization algorithms can be modified to maximize the emissions reductions from both bus operations and side traffic affected by giving priority to transit.\(^75\) Organizationally, however, this strategy is difficult because of the demands it implicitly places on ITS-deploying agencies to both measure and model emissions changes – undertaking both *ex ante* and *ex post* evaluations – and respond to that information in their operational strategies.

One can maximize possible emissions reductions from existing or planned ITS deployments through either a static or dynamic approach. The use of before-and-after studies described above is a static approach that assesses emissions impacts so that changes can later be made to the system. A more dynamic approach, on the other hand, would allow for real-time changes to be made to reduce emissions from the transportation system. This would require integration of detection technologies, such as air quality monitors to provide real-time, and perhaps location-specific information on concentrations of different pollutants. For example, the installation of air quality monitors on an urban signalized street network could enable operators at a Traffic Control Center to identify areas of high pollutant concentrations – CO for example – and modify the signal timings to clear out the traffic problem and return CO to more "normal" levels.

(3) *Deploy ITS technologies explicitly for emissions benefits*

This final approach is the most "aggressive" method for integrating emissions and air quality concerns into ITS deployment. The deployment of technologies included in the "Emissions and Environment" subsystem identified earlier would clearly fall within this approach. However, many traditional ITS technologies can also be deployed with the primary goal being emissions

\(^75\) This is also an important institutional issue, as it cuts across agencies, by deciding the level of "priority" to either transit vehicles or regular traffic.
benefits and air quality improvements. Most, but not all, of these technologies will represent "win-win" situations that bring both air quality and mobility benefits. However, there can be a large variation in terms of the relative benefits to mobility and emissions. On the far end of the spectrum are those ITS technologies that create emissions benefits, with smaller or no mobility benefits. Indeed, many of the Energy and Emissions ITS (E&E ITS) technologies would fall into this category. Figure 3-8 illustrates the relationship between these three approaches, and how they compare according to the level of innovation and experimentation with ITS technologies and their emissions benefits.\footnote{Although we will discuss these concepts more in-depth in later chapters, we consider the use of ITS for emissions benefits as innovative for two reasons. First, it entails the adoption and adaptation of new technologies not previously applied in the field of transportation. Second, it reveals a case in which a transportation agency makes deployment decisions based on goals which are not central to its traditional organizational mission. We also consider it to be experimentation when there is a dynamic process in place, with feedback between ITS deployment, operation and assessment.}

**Figure 3-8 Three approaches to incorporating emissions goals in ITS deployments**

<table>
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<tr>
<th>① Measure/model emission impacts</th>
<th>Static</th>
<th>Dynamic</th>
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<td>Some ITS</td>
<td>All major ITS</td>
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<th>② Max. emission reductions from ITS</th>
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<tr>
<td>Static</td>
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<th>③ Deploy ITS for emission reductions</th>
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<tr>
<td>Traditional ITS</td>
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<td>E&amp;E ITS</td>
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A focus toward greater “experimentation” with ITS as a tool for air quality would also require more emphasis on \textit{ex post} analysis, in addition to \textit{ex ante} analysis, as well as a greater diffusion of the results of those \textit{ex post} analysis (Farrell, Harrington et al. 1998). From the systems perspective, detailed \textit{ex post} analyses can more accurately capture some of the complex dynamics that are occurring with multiple deployments – dynamics cannot be estimated with current modeling capabilities. For example, customer interviews or surveys can be used to understand what factors may be influencing changes in mode share or use of park and ride lots, and how travel behavior is actually changing.\footnote{For example, changes in VMT can be estimated from traffic volumes, but it is difficult without \textit{ex post} analysis and data collection to determine whether VMT is changing from mode shifts, time of day changes, route changes, additional or forgone trips, or longer/shorter trips.}

Looking ahead to the case studies in Chapters 5 and 6, we will see that many public sector agencies are attempting to undertake the third approach without the supporting analytical
capabilities to know with a high level of certainty whether those ITS technologies are indeed having the intended air quality benefit. Indeed, with monetary incentives, such as the CMAQ program as an important source of funding for many ITS projects, many agencies are quick to deploy ITS for air quality benefits without the rigorous measurement and documentation needed to fully substantiate those claims.\footnote{According to an early report by Resources for the Future, “some projects slip through the cracks...in which case a logical explanation of their expected benefits is sufficient for meeting [CMAQ] program requirements” Farrell, D., W. Harrington, et al. (1998). Learning from Experiments: An Evaluation Plan for CMAQ Projects. Washington, DC, Resources for the Future: 32 pages.} As noted earlier, it also creates a bias toward \textit{ex ante} rather than \textit{ex post} studies, the results of which are generally more uncertain. Yet, the preference in the transportation community is to consider ITS as at least environmentally benign, if not actually providing benefits.

As noted by Gifford et al, “some parties may have conflicting interests in improving the level of knowledge about IVHS and its social and environmental impacts” (Gifford, Horan et al. 1992). This statement by Gifford and others represents the thinking at the early stages of the ITS program.\footnote{Although, we should be reminded that only a minority of transportation professionals that were even considering the environmental and social impacts of ITS.} Indeed, it still refers to IVHS, the acronym used during the formation of the national ITS program. While there has clearly been progress made through research institutions, universities and many public sector agencies in better understanding the environmental and social impacts of ITS, it does not address the issue of whether there are in fact “conflicting interests in improving the level of knowledge” about the impacts of ITS. While this issue has been broadly considered at the national level by research such as Gifford, Horan and others, this thesis will look at the use of new knowledge regarding the air quality impacts of ITS at the local level, in order to see whether these conflicts of interest do appear, and what their outcomes are.
CHAPTER 4. THEORETICAL BASIS AND FRAMEWORK FOR INTEGRATED INNOVATION, DEPLOYMENT AND ADAPTATION OF PUBLIC TECHNOLOGIES (IIDAPT)
4.1 INTRODUCTION

While rapid technological change creates opportunities for innovation, the pace of that technological and the increasing complexity of engineering systems challenge the ability of society to manage innovations and their impacts. This is especially true in government where "public investors and regulators face the daunting task of assessing broader security, environmental, economic and societal implications of technologies as they channel public resources into investment areas and as they make hard calls on regulatory decisions" (Oye 2005). With the emergence of new ITS technologies, public sector agencies in cities across the US had to begin to make difficult decisions regarding how to invest in the transportation infrastructure: whether to continue the traditional strategy of expansion of physical capacity; explore the use of new detection, communications and control systems to manage existing capacity; use technologies and other means to give new impetus to transit and support non-motorized travel; or a combination of all of the above. Regulatory changes at the federal level were making it increasingly difficult to follow the traditional path of capacity building, while simultaneously opening up opportunities to explore emerging ITS technologies (e.g., through funding, demonstration and pilot projects, diffusion of information regarding their benefits, and the generally lower cost of ITS technologies compared to traditional infrastructure). Furthermore, some of the regulations brought increasing pressure upon state and local agencies to identify measures to reduce mobile source emissions – measures which could also use ITS technologies directly to reduce emissions or indirectly as a supporting application.

Yet, in looking at the history of ITS and its role as a potential tool for emissions reductions in urban areas, one is confronted with a puzzle. With ITS, one would expect to find a number of possible “win-win” situations between the two problems that many metropolitan areas are facing, namely, increasingly severe congestion and the struggle to meet federal air quality goals in a timely and cost-efficient manner. The conventional wisdom of the ITS community has generally held that ITS would open up new opportunities for reconciling mobility and air quality goals. For example, from the perspective of traffic management, ITS seemed to be a rare case of actually being able to “have your cake and eat it too” in that ITS would improve level of service (typically measured by travel time, but also by reliability) and reduce delays, idling time and stop-and-go traffic via better detection and control of traffic flows. But, at the same time, these strategies were not expected to improve travel times to the extent that induced demand would be a substantial problem. On the transit side, there were hopes that more reliable operation of transit fleets, provision of real-time information to users, and an improved image of transit would attract new riders, thus reducing VMT and emissions. Information to drivers would help alleviate traffic congestion, by routing vehicles away from non-recurrent congestion caused by incidents and events, and encouraging people to travel at non-peak hours. As a result, emissions from unnecessary idling and stop-and-go travel conditions would be diminished. Finally, ITS could reduce the transaction costs for unconventional forms of travel, such as carpooling, vanpooling and carsharing, and put a price on travel through congestion charging, all of which could reduce VMT substantially. Yet, in most metropolitan areas, the current reality is a far cry from these initial promises. ITS represents a relatively low-cost investment and its use to
improve mobility is widespread. However, very few metropolitan areas have fully taken advantage of ITS to meet the dual goals of both improving mobility and reducing the impact on the environment. Therefore, some of the questions of this research are:

- Why has ITS not been used more extensively as an innovative tool for emissions reductions?
- Moreover, why have cities with both air quality problems and high levels of ITS deployment not always taken credit (e.g. as measures in their air quality management plans) for the emissions reductions that may have occurred as a result of ITS deployments?
- For areas of uncertainty regarding the air quality benefits of certain ITS applications (as identified in Chapters 2 and 3), why have there not been greater efforts to experiment with and evaluate the emissions outcomes of those technologies?

To gain insight into these issues, we will review and synthesize the theoretical literature that discusses the following four topics:

- innovation and experimentation in public sector organizations,
- the cooperation between “promoters” and “regulators” of technologies in the public sector,
- the role of technology assessment in the public sector, and
- the adaptation of public sector agencies to new and better information, such as the information generated by assessments and evaluations.

We are considering the issue of how public sector agencies manage new technologies and their deployment in a way that attempts to maximize the desirable benefits and minimize the negative impacts. In order to achieve this desired outcome, the four factors above have to be addressed. In other words, governments have to overcome the barriers to innovation and experimentation, overcome the fragmentation between technology implementing and regulating agencies, actively assess new technologies and adapt to emerging information related to those technologies and their impacts. At another level, the interests and incentives of each organization have to be aligned in a way that will enable this type of innovation and adaptation of new technologies.

As we delve deeper into the cases, we will see that it is not simply an issue of failing to implement good ideas that provide benefits to all. Indeed, we will see that these so-called “win-win” situations are not always compatible with the underlying interests of public sector organizations. Agencies may indeed have interests and agendas that go beyond a simple mission statement or vision. Therefore, we will also review the additional questions.

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What are the interests or incentives for agencies to deploy, or not to deploy, particular ITS technologies for the purposes of air quality?

What can explain the variations in how agencies produce and use new information on the impacts of ITS technologies on air quality?

What are the interests or incentives to bring to light, or even hide, new information or to adapt (or not) to that information?

Through this research, we will examine critically these issues of "win-win" situations. The policy literature, often refers to the need for policy integration, and highlights that mutual benefits and synergies that can be realized through cooperation among agencies from different sectors – transportation, environment, housing, energy, finance, etc. (Lafferty and Hovden 1997). Yet, each agency must also be treated as an entity with its own self-interest, where the self-interests may not always coincide with the general interest – even in the public sector.

The cases in the next chapter will be set up to examine why some cities have experimented more with the use of ITS for air quality, while others have done so very little. In what cases have cities been able to successfully experiment with and adapt ITS deployments as a means for air quality improvements under new federal transportation and air quality legislation and regulations, and what factors enabled them, but not other cities, to accomplish this? The cases will represent various degrees of success in addressing the four factors identified above, and ultimately various degrees of success in technology management in the public sector.

The remainder of this chapter will therefore explore theories of (1) innovation in government, (2) cooperation for multiple policy benefits, and (3) assessment and adaptation of new technologies in the public sector, drawing from and synthesizing the literature on organizational theory, political science, and public administration, as it relates to these three areas. The primary focus will be on innovation, but with an emphasis on cases where innovation requires joint action of different agencies, and where assessment is required to understand the full outcomes and impacts of those innovations, and adapt their deployments in an iterative process. Finally, we will present a framework for the management of technology and its impacts in the public sector. This concept, which we will refer to as Integrated Innovation, Deployment and Adaptation of Public Technologies, or IIDAPT, represents the following idea.

Public sector organizations cooperate to adopt and use new technologies in support of multiple policy goals. This process of innovation is iterative, as agencies assess impacts and adapt technologies to new information on outcomes.

Articulating and operationalizing this concept will also serve as a measuring stick to classify and test the cases in the following chapters. However, first we turn to the theory.
4.2 INNOVATION IN GOVERNMENT

This section will address a number of questions regarding the inherent barriers to innovation in public sector organizations. Why is it so difficult for public sector organizations to innovate? Is it really so rare? What counts as innovation in government agencies? Under what conditions will public sector agencies innovate and experiment with the adoption, adaptation, assessment and implementation of new technologies?

4.2.1 Barriers to Innovation

Organizational theorists have generally been pessimistic about the ability of public sector agencies to innovate. James Q. Wilson, a longtime observer of organizations and bureaucracy, paints a bleak picture for public sector agencies:

“We ought not to be surprised that organizations resist innovation. They are supposed to resist it. The reason an organization is created is in large part to replace the uncertain expectations and haphazard activities of voluntary endeavors with the stability and routes of organized relationships. The standard operating procedure is not the enemy of organization; it is the essence of organization” (Wilson 1989, p 221).

This outlook on the difficult of innovation reflects to a large extent Wilson’s own definition, “innovation is not any new program or technology, but only those that involve the performance of new tasks or a significant alteration in the way in which existing tasks are performed” (Wilson 1989, p 222). The stability of standard operating procedures and task definitions is central to Wilson’s theory of organizations, and is also incorporated into Allison’s “model of organizational behavior” (Allison and Zelikow 1999, pp 143, 147-8, 169-70). As a result, Wilson and Allison discard, to a large extent, the adoption of new technological developments and program innovations as merely peripheral and reversible changes, citing numerous cases in which bureaucracies did indeed adopt new, sophisticated technologies, but only because those technologies would allow them to perform existing tasks better, while resisting redefinition of those existing tasks or changes to their standard operating procedures (Wilson 1989, pp 222-224).

These theorists do suggest than innovation and change can happen the wake of crisis. Examples such as the U.S. Army in the wake of the Vietnam War and NASA’s loss of the Challenger Space Shuttle offer dramatic instances of failures in organizational practices, standard operating procedures (SOP), and culture, and thus the need and pressure to change those procedures. However, more frequently, the erosion of the effectiveness of an organization SOP’s is a much more mundane and unremarkable process, and does not necessarily reach the point of crisis or dramatic public failures or scandals. Rather, the erosion of the effectiveness and performance is due to changes in the organization’s external environment, and performance failures, large and small, point to a mismatch between the organization’s tasks and procedures, and the external environment. Therefore, as performance failures accumulate, the need for innovation becomes more intense.
The branch of organizational theory called organizational ecology, looks closely at this relationship between the organization and the external environment. These theorists tell a somewhat different story, in many ways even more pessimistic than that of Wilson, suggesting that there are strong internal and external inertial pressures that both support organizational stability (Hannan and Freeman 1977; Hannan and Freeman 1989). Not only is internal organizational inertia strong, but organizational change can degrade performance and threaten survival due to external pressures. According to this model, organizations showing high reliability and accountability are “selected” — borrowing a metaphor from biological ecology — over more variable organizational forms that have higher failure rate. Therefore, organizations that change, are less likely to survive, at least in the private sector, as they are more liable to fail. This is a surprising result for those convinced of the notion that innovation is almost unequivocally beneficial to the organizations that undertake it.

Nonetheless, more recent empirical studies from organizational theorists have challenged both the principles of inertia and the effect of organizational change on performance. Haveman, in her study of the California savings and loan industry, looked at the organizational responses to rapidly changing environmental conditions — technological, economic and regulatory shifts. The results indicated that when environmental conditions change rapidly, organizational change can enhance both the near-term performance and long-term survival of the organization. She suggests that sharp changes in environmental conditions can pose a risk to organizational survival, since this “transformation of environmental conditions renders previous organizational strategies and orientations obsolete” (Haveman 1992, p 51). However, an important corollary to this study, was that the impact of organizational change also depends on the “degree to which new activities are related to existing competencies” (Haveman 1992, p 51). This means that organizational change has benefits for organizational performance when the environment around it changes, but that performance is best when drawing upon the competencies and capabilities of the organization.

4.2.2 What Counts as Innovation?

An important issue that arises is what counts as innovation in public sector organizations. Schumpeter’s classic work on innovation and economic development laid down definitions for innovation in the private sector that included: new products, new methods of production, and the opening of new markets, new sources of supply and new organization of an industry (Schumpeter 1934). These definitions have been modified and expanded over the decades (for example, to apply to the service sector in addition to manufacturing), but the basic notion of innovation as novelty in products, processes, applications, and organization has endured. Although this early definition included organization (at the industry level) as a form of innovation, the major focus of the literature on private sector innovation has been on technological innovation in products and process, with a focus on organizational innovation

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81 Wilson, although not optimistic about the potential for innovation in public sector organizations, did at least recognize the potential for external and internal factors to bring about substantive changes.
82 More specifically, the regulatory change was deregulation of the industry.
emerging only to the extent that it can explain successes or failures in bringing product and process innovations to fruition.

The literature on innovation in the private sector has proliferated – both the “didactic literature” offering advice and prescription for how to manage innovation, and the social science literature using empirical evidence to explain the “phenomenon of innovation” (Lynn 1997). However, the literature on innovation in the public sector has lagged. As a result, there is often an attempt to distill lessons and transfer theories developed in the more enterprise-oriented innovation literature to the public sector, often with several points of mismatch. Because public sector organizations are not usually in the business of bringing products and services to a competitive market, the definition of innovation has to tended ignore the technology side of public sector innovation, with a predominant focus on innovation in organizational routines and structures. In addition, while the core goals and objectives of private sector organizations are relatively clear and non-contested, government agencies do not enjoy this luxury, and often face a conflicting and ambiguous set of goals and priorities (Wilson 1989, p 115; Allison and Zelikow 1999, p 149).

This relative lack of literature on technological innovation or adoption and adaptation of new technologies by the public sector has several consequences. First, in defining innovation for the public sector, because the technology aspect is often disregarded, the bar is set high for what does and does not count as innovation. Innovation is equated more narrowly with organizational innovation – a much more difficult form of innovation to undertake, as discussed above. For example, according to Lynn, “innovation is properly defined as an original, disruptive, and fundamental transformation of an organization’s core tasks. Innovation changes deep structures and changes them permanently” (Lynn 1997, p 96). Second, innovation in government agencies is not always looked upon as desirable to the extent that innovation can set up conflict with goals of accountability to their principals (elected officials in the legislative and executive branches) as well as to the public (Behn 1997, pp 10-11). Innovation is seen as possibly crossing the division between creating policy (the domain of legislators and other elected officials) and administration, or “simply” carrying out policy (the domain of bureaucracies). Finally, the

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83 ITS is an exception, in that public sector organizations not only implement new technologies, but also develop products that may be provided by the private sector as well, such as real-time traveler information.

84 This is reminiscent of Wilson’s definition of innovation. In fact, both Lynn and Wilson arrive that the same conclusions, that in order to improve government performance and innovativeness, it is necessary to deregulate the public sector. Wilson, J. Q. (1989). Bureaucracy: What Government Agencies Do and Why They Do It, Basic Books.


85 Many scholars have pointed out the artificiality of this division between politics and administration, which was eloquently described by Woodrow Wilson over a century ago. Wilson, W. (1887). “The Study of Administration.” Political Science Quarterly 2(2): 197-222. They suggest that because legislation and other policy mandates do not contain specific instructions on how to carry them out administratively, there is room from some innovation in not only how policies are carried out, but what those policies actually mean. Behn refers to this as the “fallacy of legislative clarity.” Behn, R. D. (1987). “A Curmudgeon’s View of Public Administration: Routine Tasks, Performance, and Innovation.” State and Local Government Review 19(2): 54-61.
"remedy" offered to those who wish to promote greater innovation in government is to make the public sector more like the private sector (Osborne and Gaebler 1992).

Therefore, returning to the earlier question: What counts as innovation in the public sector? Wilson and other organizational theorists, as noted earlier, only count major changes in core tasks and thus in the organization itself. Therefore, one can say that the most difficult and less frequent form of innovation, according to the theories outlined above, is organizational innovation, or changes in the core tasks of an organization. However, in the public administration literature, two other types of innovation have been identified: policy innovation, which is the creation of new policies, services, and programs by administrative agencies, and legislative innovation, which is the adoption of new laws and statutes by the legislature. Finally, the category of innovation that will be of most interest for this thesis is technological innovation. However, there are various degrees of technological innovation. Major innovations (also described as radical, disruptive, or breakthrough) represent technological developments that completely break from existing technology trajectories. Incremental innovations, on the other hand, represent more gradual, continuous improvements to already-available technologies, which are adapted from one organization to another. Finally, diffusion, is the adoption of existing technologies without adaptation, although some theorists of innovation would argue that they are indistinguishable.

However, it should be recognized that this a highly linear model of technological change. According to Mytelka, theorists such as Rosenberg broke new ground in looking at the feedbacks in the innovation processes, suggesting that "innovations... invariably require major post-innovation improvements, and it is these that shape adoption. This undermines the distinction between innovation and diffusion" (Mytelka and Smith 2002, p 1472).86 We will define technological innovation broadly as the implementation of technologies that are new to the agency, whether that implementation involves the adoption, adaptation, or development of a new technology, noting that innovation is a non-linear and adaptive process.

Any typology of innovation will encounter cases that defy easy categorization, and often, innovations will span two or more categories. For example, in surveying innovations in policing, four categories of innovation were identified: programmatic, administrative, technological and strategic (Moore, Sparrow et al. 1997, pp 277-280).87 However, the authors add that all

86 In the literature on state policy and legislative innovations, diffusion is often used as a term relatively interchangeable with innovation. Diffusion describes the process of transfer and adoption of innovations from state to state. However, as long as the policy or legislation is new to the state adopting it, it is considered an innovation. Walker, J. (1969). “The Diffusion of Innovations Among States.” American Political Science Review 63(3): 880-899. Gray, V. (1973). “Innovation in the States: A Diffusion Study.” American Political Science Review 67(4): 1174-1185.

87 Briefly paraphrasing Moore et al’s definition, programmatic innovations are new operational methods, administrative innovations are changes to how agencies prepare for operations (training) or measure performance, while strategic innovations are fundamental changes in the mission, goals, and orientation of the agency. Technological innovation is the adoption of new capital equipment. Moore, M. H., M. Sparrow, et al. (1997). Innovation in Policing: From Production Lines to Jobs Shops. Innovation in American Government: Challenges,
technological innovation also fall within one of the other three categories of innovation, since a technological innovation is defined not by "its purpose but the material in which the innovation is embedded" (Moore, Sparrow et al. 1997, p 279). Furthermore, taking innovation as a dynamic and nonlinear process, adoption of new technologies cannot be seen as a one-time event. Technologies that are initially adopted as a minor programmatic innovation in order to complete existing tasks more efficiently or effectively than before, may open the doors for more fundamental strategic innovations and agency reorientation. In this sense, implementation of new technologies can be a trigger for deeper organizational change. Wilson provides us with some vivid examples from the military. For example, before WWII, when navies were purchasing aircraft, they did so as a means to improve reconnaissance, literally "to extend the vision of the battleship's captain." However, the use of aircraft by the navy eventually led to an entirely new form of naval warfare with "carriers deployed in fast-moving task forces" (Wilson 1989, p 222). Therefore, following the adoption of this new technology, requiring little or no change to existing task structures or standard operating procedures, once experience with the new technology was gained, it enabled a redefinition of organizational tasks and strategies. However, without the adoption of the technological artifact, the aircraft, and the new organizational capabilities that it brought with it, the more profound organizational change would not have occurred.

4.2.3 Factors Influencing Public Sector Innovation

The reasons for innovation by public sector organizations are unfortunately not as apparent as the basic reason for private sector innovation – i.e. survival in the marketplace, competitive success, and profitability. Behn suggests several possible reasons why government agencies innovate: (1) because business does it, (2) because government's standard operating procedures are proving inadequate, (3) because government needs to improve performance, and (4) because all organizations need innovation (Behn 1997). The first and last reasons are not factors that can explain in any satisfactory manner why some public sector agencies innovate, while others do not, since these conditions would be equally applicable to all organizations. Therefore, under what conditions do a government agency's standard operating procedures and performance prove to be inadequate, and thus lead to change and innovation?

Referring to the cases of innovation in the public sector, Wilson notes that pressures for change can be "externally imposed or internally generated" (Wilson 1989, p 227). Citing important innovations in the military – the air force's adoption of the intercontinental missile, the army's incorporation of a counterinsurgency unit, and the navy's acceptance of a submarine launched missile program – he suggests that outside forces from academic, industry, Congress, and the executive branch played a key role in bringing about changes in the military branches that did indeed alter core tasks (Wilson 1989, p 225).

Public sector organizations at the state, city and county level present an interesting case for several reasons. First, government agencies are not subject to the same survival pressures as

private sector companies. Government agencies are initially “called into being by political processes” (Allison and Zelikow 1999) but are much harder to dissolve, or even see their growth checked by these same processes, given that these bureaucracies can be characterized as taking on a life and purposes of their own.88 Second, although their survival may not be threatened in the same way as that of private sector organizations, through direct competition, the continued adequacy of the standard operating procedures can be drastically affected by legislative or political changes and public pressure. Finally, for local and state government organizations, the adequacy of their SOP depends both on the state legislature and state and local elected officials, as well as the changes brought about through federal legislation and regulations. Thus, changing federal policy goals or tightening the regulations on the usual activities of state and local public sector agencies can spur innovation by forcing agencies to break out of their usual tasks and programs and seek new solutions to problems.

In this thesis, we focus on the specific case of when federal agencies and federal legislation create both new constraints and opportunities for local and state agencies. Indeed, the federal legislative changes that occurred at the federal level for transportation and air quality planning were themselves innovations, by linking the approval and funding of regional transportation plans and programs to their ability to meet national air quality standards and providing funding mechanisms for transportation-related air quality projects through the CMAQ program. Through legislation and regulation, the federal government determines the “rules that constrict the range of governmental decisions and actions that are acceptable” (Allison and Zelikow 1999). Changes in these rules can therefore challenge the adequacy not only of the SOPs, but of the programs and priorities of the local and state level organizations. Furthermore, changes in the federal rules that bind state and local agencies are often reinforced with changes in funding relationship between the federal government and states. Stone, in her study of innovations in health policy, suggests that state innovation can be highly influenced through the federal government through the use of “carrot and cudgel,” with innovations “often forced on the states either through legislation or slightly more gently through strings attached to federal Medicare and Medicaid money” (Stone 1997, p 221).89

Many observers in different fields have noted that the US federal system presents 50 laboratories (i.e. the states) for experimentation and innovation. Research in the area of public administration has looked at how states respond to federal environmental regulations, for example, whether the states merely comply or whether they initiate new laws and policy or program innovations of their own (Potoski 2001). There have been a number of studies assessing the determinants of both policy and legislative innovation and diffusion of innovations in the states (Walker 1969; Gray 1973; Sapat 2004). The most well-developed literature on innovation in government is that focusing on legislative innovations.

Walker identified several possible variables that could explain the level of legislative “innovativeness” of the states. One important factor was wealth, or more specifically, “the

88 For example, one of the early and influential studies on the growth and budget-maximizing tendencies of the public bureaucracy is William Niskanen. 1971. Bureaucracy and representative government. Chicago, IL: Aldine.
89 More commonly referred to as the less euphonious “carrots and sticks.”
degree to which ‘free floating’ resources are available, ... If ‘slack’ resources are available, either in the form of money or a highly skilled, professional staff, the decision makers can afford the luxury of experiment and can more easily risk the possibility of failure” (Walker 1969, p 883). This concept of organizational slack was draw from Cyert and March’s seminal book, *A Behavioral Theory of the Firm*, first published in 1963 (Cyert and March 1992). Researchers have debated whether “slack” leads to higher or lower levels of innovation (Nohria and Gulati 1996). Walker applied the idea of slack resources to the state level, with the hypothesis that the states most likely to innovate, would be the larger (population), wealthier states, and that the “great cosmopolitan centers” would be the most open to innovation. In addition to wealth, Walker identified political variables such as the turnover in office, party competition, and legislative professionalism. Although focusing more on diffusion than the determinants of innovation per se, Gray also found that innovative states were wealthier and more competitive (Gray 1973). However, a drawback to these studies is that the focus is more on factors that increase the capacity of states to adopt innovations, leaving aside to a large extent of what motivates them to innovate in the first place.

The literature on policy and program innovations (as opposed to legislative innovations) brings us somewhat closer to understanding the motivations for innovation. Here, the principal actors are the administrative agencies. For example, one of the more recent studies in this area looks at environmental policy innovations undertaken by state administrative agencies in the area of hazardous waste (Sapat 2004). This examines a broader set of factors than those offered by Walker and Gray, and acknowledges to a greater extent the external pressures that lead state agencies to adopt innovations. Sapat developed a model drawing from the literature on state environmental regulation and state innovation, identifying four factors: (1) the severity of the problem, (2) institutional factors (the commitment (financial) and capacity of the states), (3) the strength of relative interest groups, and (4) contextual factors, such as state political climate (Sapat 2004, p 144). The empirical results indicate that need/problem severity and institutional factors (in particular, staffing levels and state wealth) are statistically significant indicators of the probability of adopting and implementing innovations. On the other hand, interest groups and contextual political factors do not seem to have a strong impact on the level of policy innovation. It is also interesting to note how Sapat diverges from Gray and Walker on the issue of wealth. While the more common view is that more wealthy states can “afford” to adopt policy innovations Sapat suggests that the relationship could go in either direction, as states that are less wealthy may also adopt policy innovations in order to create new resources, such as through fees and fines imposed (Sapat 2004, p 145). However, her statistical results indicate that wealthier states are more likely to innovate.

These studies also point to the importance of staffing levels or staff professionalism as a factor in innovativeness. Walker considered having an “extensive staff and research facilities in their legislatures” a factor that explained why some states adopted innovations more readily, at least in terms of legislative innovations (Walker 1969, p 885). Sapat also considered administrative capacity to be a determine of program innovation, using the variable of the number of full-time

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90 In the transportation sector, there has been a recent focus on “innovative financing” in order to place the current system of federal-aid grant financing for highways based on gasoline tax revenues.
employed staff as a measure of capacity. Her argument is that “if a state has more staff working on a state program, its ability to implement innovations is enhanced” (Sapat 2004, p 144). Presumably, this argument can be extended from state agencies to city, county, and metropolitan agencies and organizations. However, when the innovation includes the deployment of new technologies, not only the absolute staffing levels, but the composition of that staff and their education and professional capability, are important. Sussman discusses the importance of the education of the “new transportation professional” as a necessary prerequisite for transportation organizations to be able “reinvent” themselves (Sussman 1995). According to Sussman, transportation professionals must have both breadth in technology, systems and institutions, and depth in their transportation specialty, in order to advance both organizational and institutional change (Sussman 2001). Zegans suggests that “creative ideas can come from anywhere,” both at the civil servant levels and managerial positions (Zegans 1997, p 112). This would suggest, that the education and professional capability of individuals within the agency at all levels, are important conditions for innovation. One could further suggest that for technological innovation, the technical background of full-time staff is a key component for success.

However, the process of change in the staff and management of public sector agencies can be slow. First, the need for changes in the training and educational requirements of public sector staff and managers can be a barrier, since universities, like most organizations, are also slow to change. Therefore, universities will often lag in changing their curriculum and programs in response to the needs of future employers. Furthermore, time is needed for several generations of graduates to complete their education and be incorporated into the workforce.

Returning to the idea of wealth as a factor determining levels of innovation, the issue of budgetary resources as a factor influencing innovation is also taken up by Allison and Zelikow, who offer three conditions under which organizational learning and change can occur. First, they suggest that both a “budgetary feast” and “prolonged budgetary famine” can result in fundamental changes in the organization. They also suggest that “dramatic performance failures” can shock the existing organizational culture into change (Allison and Zelikow 1999, pp 171-2). Although these three conditions, drawn from the organizational behavior paradigm, are not elaborated in greater depth in Allison and Zelikow, it is interesting to compare them to theories discussed above. While the above mentioned studies suggest that the wealth or resources of a state are important factors in policy and legislative innovation, they have assumed resource levels to be relatively static. Allison and Zelikow’s observations, however, also point to the importance of changes in resource levels, whether positive or negative, as a spur for organizational change.

Yet, whatever the motivations for innovation in the public sector are, a fact of administrative life for public bureaucracies is that successful actions often require coordination with other levels of government, or other agencies with overlapping or otherwise related functions. Therefore, in the following section, we will define and discuss the virtues and vices of fragmentation, and mechanisms to overcome it.

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91 However, some public managers interviewed noted that innovations were more likely to come civil servants.
4.3 COOPERATION FOR MULTIPLE POLICY BENEFITS

While the public, press and politicians often decry the fragmentation of responsibilities in government, defined here as the lack of coordinated action between agencies, and the inability to cooperate, it is important to ask: Why does fragmentation exist in the first place? What role does it play both for organizations and for society at large? What are the strategies to deal with fragmented and decentralized public sector agencies in the face of the need for coordinated action, and under what conditions will agencies overcome fragmentation?

4.3.1 The Benefits and Problems of Fragmentation

As described by Allison and Zekilow, there is a dilemma between decentralized power and coordinated action. “Governmental action requires decentralization of responsibility and power. But problems do not fit neatly into separable domains” (Allison and Zelikow 1999, p 172). The decentralization and fragmentation of responsibilities into separate agencies is critical to the performance of government functions, as it provides a division of labor and specialization that enables specific tasks and purposes to be carried out more efficiently. Each organization or agency within the bureaucracy has responsibility for a specific set of tasks and problems. Max Weber, one of the early and most influential organizational theorists, suggested that organizations were, in fact, highly efficient instruments for achieving goals (Allison and Zelikow 1999, pp 148-9).

In addition to the efficiency argument, decentralization and fragmentation in the bureaucracy serves as a balance between various interests and values in society. Lindblom, in his landmark article “The Science of ‘Muddling Through,’” looks at the decision-making process as a method of successive limited comparisons, building out incrementally and continually from the current situation. Given that an administrator or agency cannot possibly take into account all of the possible repercussions of their policies—economic, social, environmental—they must simplify their analysis and essentially ignore many of the impacts of their actions. However, the remedy for this lack of comprehensiveness is the fragmentation of decision-making into that agencies will represent different values. As described by Lindblom:

“Suppose that each value neglected by one policy-making agency were a major concern of at least one other agency. In that case, a helpful division of labor would be achieved, and no agency need find its task beyond its capacities. ... The virtue of such a hypothetical division of labor is that every important interest or value has its watchdog” (Lindblom 1959).

Agencies can redress damages already done by other agencies, or anticipate and “head off” pending injuries. According to Lindblom, the result is a “process of mutual adjustment” between different government agencies and with other groups representing societal values.

This concept of “watchdogs” for each interest, is also evident in the division between technology-promoting agencies and regulatory agencies in government (Rip, Misa et al. 1995, p 2). For example, during the 1950s and 1960s, the inability of the US Atomic Energy Commission to address the risks involved with its development of nuclear power, lead to the
separation of its promotion and control activities, dividing these distinct activities into the Department of Energy and the Nuclear Regulatory Commission (Hewlett and Holl 1989; Rip, Misa et al. 1995). The relationship between these two organizations is obvious, as it is centered on the generation and control of risks from nuclear energy. However, for other technology-promoting and regulatory agencies, the link may be less clear, particularly when dealing with complex systems, where the link between the regulator and the regulated is not always direct.

The complexity of the links from activities to impacts, often makes it difficult to control the risks created by a technology-promoting organization. This complexity can arise because of the time lags between actions and impacts (temporal disconnect), the distance between actions and impacts (an action at point A, has repercussions at point B, spatial disconnect) and the difference in the characteristics or nature of actions and impacts (substantive disconnect).92,93 An example of the spatial and substantive disconnect is acid rain. While advances in atmospheric science and modeling have clarified this now “obvious” connection, there is a spatial disconnect, in that activities in one country can have an impact on the environment in another county. There is also a substantive disconnect, in that industrial production processes and power generation can lead to acidification of the soil, through complex chemical and transport phenomena. Finally, there is a temporal disconnect because the processes leading from emissions to soil acidification take time, particularly when there is transport of pollutants across longer distances.

Another example is transportation conformity. In the early 1900s, when the concepts of urban sprawl, induced vehicle travel from highway expansion, and ozone formation were unknown, it would have been inconceivable to expect air quality agency to have a control function over whether and how to build urban highways. However, as these relationship became more clear, in terms of the role of new transportation capacity and low-density land use patterns and their effect on regional vehicle miles traveled, there was pressure to regulate these impacts.94

Turning back to organizational theory, in addition to the broader societal value of fragmentation - the division of labor and balance of interests - there is also an intrinsic value to the organizations themselves of allowing an organization to focus on its core mission and values. According to Wilson, when agencies are responsible for more than one goal and therefore realize various tasks, “they will have competing cultures that cannot easily be fused into a shared a sense of mission” (Wilson 1989, p 96). This sense of mission provides a sense of “common worth” to its members, allows for a unified control over task definitions, improves the internal flow of information, and provides non-monetary benefits to its members which generate enthusiasm and reduce the shirking of responsibilities (Wilson 1989, p 95). Therefore, imbuing an agency with too many competing goals - such as promoting a technology and regulating its impacts, can undermine this sense of mission. For example, in attempting to explain the

92 Joseph M. Sussman (Massachusetts Institute of Technology), personal communication with author, November 26, 2005.
93 These disconnects can also occur many other policy settings, such as a changes in health policy and the impact on crime rates.
94 Indeed, this leads us to the question of whether the level of complexity of an engineering system is an inherent characteristic, or at least partially a function of our level of understanding of the system. We will later discuss the idea of so-called “emergent” behavior, which may point to the inherent complexity of certain systems.
organizational barriers to intermodal transportation planning and policy, the issue of organizational culture must be addressed. As noted in a report by the Transit Cooperative Research Program, "Highway and transit agencies have historically strengthened their *esprit de corps* by reinforcing the importance of their individual mode and organizational purpose" (Crain and Associates 1996).

The problem with fragmentation is that problems do not fit into boxes. Interdependencies exist, and the actions of one agency may have negative (or positive) repercussions, direct or indirect, that affect other agencies. Although Lindblom's model of mutual adjustment provides one means of providing comprehensiveness in decisionmaking, many decisions and actions require a more concrete form of interaction. Yet, joint decisionmaking is difficult. Even when the goals are clear and everyone is in apparent agreement with a particular program, the large number of actors involved in the numerous steps from idea inception to implementation, leads to what Pressman and Wildaskvy called the "complexity of joint action" (Pressman and Wildavsky 1984). Even with a 99% chance of success at every step in the decision process, with a large enough number of actors – at the federal, state and local level – and thus an enormous list of decisions to be made and approvals to be secured, the overall probability of program success may be low. Furthermore, there may be power asymmetries between agencies, meaning that mutual adjustment does not occur, and the more powerful agency, which has negative impacts on the weaker agency, cannot be persuaded either to "adjust" their actions or cooperate with the other agency in a process of joint decisionmaking.

4.3.2 Overcoming Fragmentation

The call for greater policy integration is especially strong in the area of environmental policy, and in particular, sustainable development. Greater policy integration is seen as essential to "remove contradictions between policies" as well as to "realize mutual benefits and make policies mutually supportive" (Lafferty and Hovden 1997). One of the policy sectors that has been increasingly required to take on environmental policy objectives in addition to its own internal policy objectives, is the transportation sector. In the US, the CAAA and ISTEA linkages were an attempt to motivate/mandate this type of environmental policy integration in local transportation investment and decisionmaking.

Transportation and air quality management in metropolitan areas is a highly fragmented policy arena. As highlighted by Wachs and Dill,

"There is now in most metropolitan areas a regional body that focuses on transportation funding, planning, and policy making, while major highways continue to be built and operated by state agencies, local streets and highways by cities and counties, and transit services by municipal or county transit authorities" (Wachs and Dill 1997)

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95 For example, according to Lafferty and Hovden, "one of the key defining features of 'sustainable development' is the emphasis on the integration of environmental objectives into non-environmental policy-sectors." Lafferty, W. M. and E. Hovden (1997). "Environmental Policy Integration: Towards an Analytical Framework." *Environmental Politics* 12(3): 1-22.
Add to this mix the state environmental agencies and air quality districts, as well as the federal government agencies responsible for transportation and the environment. The result is a complex network of public sector agencies dealing with different domain issues and levels of jurisdiction.

Three types of relationships can be identified as part of the networks responsible for delivering government services: (1) intergovernmental, or the federal-state-local interaction; (2) interagency, or agencies within the same level of government; and (3) private-public partnerships (Gormley and Balla 2004). For the purposes of this thesis, we will focus primarily on the horizontal interagency relationships. However, interagency relationships cannot be understood without also taking into account the intergovernmental dynamics. We are also interested in how the federal government influence the conditions that determine how agencies at the state and local level interact.

In this case, it is useful to turn to North’s distinction between *institutions*, which are the formal and informal “rules of the game” for how organizations interact, and *organizations*, which are the “players in the game” (North 1990). More concretely, but in a similar vein, Sussman describes institutions as the connections and relationships among organizations, such as inter-organizational structures and partnerships (Sussman 2001, pp 25-26). For this thesis, we use the word *organizations* as referring to individual government agencies, private sector companies, or non-governmental organizations, while the *institutions* are the processes, structures, and outputs that require the actions of more than one organization. As a general rule, organizations are easily identified and “named” – State Departments of Transportation or Environmental Quality, the Federal Bureau of Investigations, the Environmental Protection Agency, Metropolitan Planning Organizations, City Public Works Departments, and so forth. However, institutions are more nebulous entities, and thus more difficult to name. In the context of this thesis, examples of institutions include the long-term transportation planning process, air quality conformity determination, interagency working groups, and regional ITS architectures.

In terms of interagency interactions, at the most basic level, there are two forms of dealing with interagency fragmentation: (1) an agency can absorb specific tasks and responsibilities that belong to other agencies, (2) the agencies can cooperate and coordinate their actions. According to Wilson, both are typically difficult for public sector agencies, because they can represent threats to an organization’s much prized autonomy. Running counter to Niskanen’s and others arguments that agencies are always seeking to expand their size by “taking on new functions and gobbling up their bureaucratic rivals,” Wilson suggests that agencies are wary of taking on new tasks, particularly tasks that are unpopular, difficult, or substantially different from their mission (Wilson 1989, pp 180-1, 190). Similarly, agencies will also be hesitant to cooperate and coordinate actions formally, because of the possible threat to their autonomy. Maintaining autonomy also means that agencies will resist being regulated by other agencies (Wilson 1989, p 193).

Yet, despite the odds, coordination and cooperation can and does occur, although with highly varying levels of success. In a carefully detailed case study of transportation agencies in the San Francisco Bay Area, Chisholm found that given the strong interdependencies between agencies...
providing transit service, informal modes of cooperation were developed, and proved to be both stable and effective forms of cooperation both under normal circumstances and crises (Chisholm 1989). The informal nature of the relationships, following Wilson’s logic, would have provided a guarantee to the ultimate autonomy of each agency. In terms of more formal cooperation, efforts to coordinate various agencies include task forces, committees, councils, boards, and, in the more extreme cases, the creation of “czars” (Wilson 1989; Gormley and Balla 2004). These vary in their degrees of control, and to what extent they are formed for purposes of information sharing, arbitrating disagreements between agencies, or coordinating joint actions.

While these different forms of coordination are typically imposed by executive branch leaders, there are also more bottom-up networks of agencies. Organizational theorists have reached the reasonable conclusion that “relations form when members of two or more organizations perceive mutual benefits or gains from interacting” (Schmidt and Kochan 1977, p 220). This represents the exchange perspective on interorganizational relationships. On the other hand, organizational theorists from the power-dependency camp have emphasized that the desire to interact is not shared equally, however, if the motivated party is powerful enough, it can induce the other to interact. Schmidt and Kochan, attempt to reconcile these two views, suggesting that these relationships are often mixed-motive situations, “in which each organization behaves in accordance with its own self-interests” (Schmidt and Kochan 1977, p 220). Therefore, when dealing with horizontal interagency relationships, coordination is relatively “easy” when there are mutual benefits to be gained. However, for more asymmetric power relationships, either the more powerful party can induce the other to interact, or, in intergovernmental context, the federal government can change the relative power relationships among the different agencies, in essence, generating a top-down institutional change. Therefore, interorganizational relationships can take many forms, whether mandated by law, based on formal agreement, or voluntary (Hall, Clark et al. 1977). Chisholm’s analysis also highlights that there can be a spectrum of formal and informal interagency relationships, and that often a hybrid of formal and informal networks can form between numerous agencies (Chisholm 1989).

Finally, there is the question of cooperation between two agencies, versus cooperation between a network of numerous agencies. According to Pressman and Wildavsky, in their study of implementation, the greater number of agencies involved, the lower the probabilities of successful implementation (Pressman and Wildavsky 1984). The logic of their argument is that joint action – between federal, state, county, local, and private sector agencies – is difficult and likely to fail because of the “interaction of their various rules and routines” (Allison and Zelikow 1999, p 159).

An alternative view on barriers to cooperation can be drawn from the political economy literature on externalities and the management of common pool resources – i.e. depletable natural or human-made resources. The reasons for why individual actions can lead to sub-optimal outcomes regarding the common good were first described with Hardin’s “Tragedy of the Commons” (Hardin 1968). In the case of the “commons,” the question is how to limit individual
consumption or use of a common pool resource to the socially optimal level. Similarly, with the production of public/collective goods and common pool resources, there is a tendency to free-ride upon the efforts of others, leading to underprovision. For example, Olson described how free-riding can differ according to whether interests are diffuse or concentrated (Olson 1965). According to him, the greater the number of actors, the harder it will be to mobilize those actors on a common effort that should, in theory, bring benefits to all. For more concentrated interests, the benefits of cooperation will fall on only a few, therefore the likelihood of successful collective action increases. If the cost of cooperating outweighs the benefits that will accrue to participants, there will be a socially sub-optimal level of cooperation. Therefore, the number of actors is considered as one explanatory variable for levels of cooperation.

However, Keohane, Ostrom and others, in a book that examines the convergence of the literature on local common pool resource problems and international regimes for cooperation, focus not only on the number of actors, but also on the degree of heterogeneity of those actors (Keohane and Ostrom 1995). For both local common pool resources (CPR) problem and international regimes, there is general agreement that a larger number of actors increases the difficulty of creating cooperative arrangements. However, the various case studies presented in the book also consider the question of whether heterogeneity in the capabilities, preferences, information and beliefs of those actors can facilitate or inhibit cooperation. The CPR literature generally holds that heterogeneity makes cooperation more difficult, while the international regime theory indicates that heterogeneity can help, particularly is there is a lead actor (a larger or more powerful participant that can bring the others into a stable pattern of cooperation).

In summary, it seems that Lindblom’s model of mutual adjustment may not be enough to produce socially optimal outcomes. Coordination between organizations, particularly between technology-promoting and regulating agencies can be difficult because of the concerns with autonomy and the desire to focus on their core mission and tasks. Furthermore, the difficulty may be multiplied with a greater number of agencies. With more actors, the likelihood of successful cooperation will be diminished due to the complexity of implementation and the tendency for free riding upon the efforts of others. Both organizational and institutional change are required for innovations whose adoption and implementation requires the joint action of more than one organizations. That institutional change can either be bottom-up, in which the local actors redefine their relationships with one another, or top-down, in which institutional change comes from the federal government.

96 The common pool resource can range from a pasture for grazing animals (too many animals degrades the pasture), to a highway for private automobiles (too many automobiles degrades the level of service of the highway through congestion).
4.4 ASSESSMENT AND ADAPTATION OF NEW TECHNOLOGIES

Finally, we come to the issue of assessment and evaluation of technological innovations and their impacts, and adaptation to new and better information. Under what conditions will public sector agencies undertake assessments of their investment in and deployment of new technologies? How do agencies use information to improve outcomes of current and future technology deployments? What impacts will they consider? In the face of uncertainty about both the positive benefits and the negative impacts of a given technology or system, why is it that assessments are not always undertaken or used? Do organizations adapt to the information and new insights gained from assessments, do they continue on their original course of action, or do they adapt to information unrelated to the assessments?

4.4.1 Evaluating Innovations

In general, public sector organizations have a spotty record of evaluating the results of their own programs and projects. Unlike the private sector, the efficiency criterion cannot be applied rigorously, because governments also have to take into account the distributional effects of their programs and policies (Wilson 1989, p 348). Also, what counts as success or not, is subject to how objectives and goals are defined, as there are political and organizational motivations behind the choice of performance indicators. In order to ensure “success” of innovations, organizations may choose a wide range of indicators of performance to cast the net more extensively. With multiple objectives and performance measures, even if the central goal or purpose has not been fulfilled, the organization or organizations involved in the experiment can point to some evidence of success (Pressman and Wildavsky 1984). Wilson has noted that the existence of “multiple and vague objectives” often leads to “self-congratulatory conclusions that are written by program administrators” (Wilson 1989, p 348, 375). Therefore, if an innovation can be justified according to a range of possible benefits—without a single, clear metric of success or failure—then successes can be further amplified and failures attenuated.

4.4.2 Assessing Impacts

One issue is the evaluation of the performance an innovation (according to its outcomes), while another issue is the assessment of its possible external impacts, which may be unintended and often unforeseen, and may affect other actors and stakeholders beyond the implementing organization. Many forms of assessment methodologies have been associated with the need to understand and measure the impacts of technologies on the environment. Technology assessment (TA), environmental impact assessment, integrated assessment, and risk assessment all have had important connections in trying to understand, prevent and/or mitigate environmental damages. For example, the Congressional Office of Technology Assessment (OTA), established in 1972 and closed down in 1995, represents one of the early adoptions of the formal practice of technology assessment, with the primary purpose of OTA being to provide

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Risk assessment may be the exception, since the emergence of the fields of risk analysis and management was closely related to the concerns about the safety of nuclear reactors. For this reason, issues such as the “dreadfulness” and “controllability” of risks are important considerations in risk perception and therefore risk management.” Morgan, M. G. (1993). “Risk Analysis and Management.” Scientific American July: 32-41.
Congress with scientific and technical advice independent of that of the executive branch (Kunkle 1995). However, the pro-environment climate of public opinion at the time the OTA was established led to a focus on the assessment of the environmental consequences of new technologies.98

Technology assessment, as conceived in the formulation of the OTA, would act as a monitoring or early-warning device, and thus took the approach of evaluating a wide range of possible short and long-term implications — environmental, social, economic and political — of specific emerging technologies (Kunkle 1995). However, technology assessment has a broad range of other purposes and applications in both government and the public sector. For example, technology assessment has also been a type of technology-scanning tool of government in order to determine which technologies to invest in, for example, the Advanced Technology Program of the Department of Commerce, which focused on the competitiveness of U.S. technology companies. However, we will focus here on technology assessment as a method to evaluate impacts on the environment.

Integrated assessment (IA) is another branch of assessment activity that has emerged in the attempt to provide relevant policy advice on highly complex problems requiring multiple disciplinary perspectives. The area of integrated assessments was developed around the creation of integrated modeling of complex environmental problems — issues such as acid rain, global climate change, and sustainable regional development (Dodder and Connors 2000). The intent of integrated assessments was to provide interdisciplinary and policy relevant advice on very specific (primarily environmental) problems, contrasting with the OTA approach of focusing on technologies and the wide range of potential implications.

Finally, probably the most ubiquitous form of assessment is the environment impact assessment, although this has traditionally not been directed at technology, but rather at infrastructure projects. The National Environmental Policy Act of 1970 mandated the development of environmental impact statements (EIS) for major projects, requiring public hearings on impacts and opening the door for lawsuits by citizens and environmental organizations. Therefore, environmental impact assessments, as opposed to other forms of assessments, was given a critical regulatory role through their embodiment in EIS.

4.4.2.1 Myopia and Emergent Properties

Technology and environmental assessments are not renowned for their ability to identify long-term impacts, particularly in socio-technological systems. This is especially true when considering not simply individual technologies, but engineering systems that can have long-term

98 Emilio Daddario, Chairman of the Science, Research and Development Subcommittee of the House of Representatives, was a critical figure in the establishment of the OTA. Daddario envisioned Technology Assessment as a tool to better manage technology and the environment. In lobbying for its establishment, Daddario argued, “The most glaring example at the moment is environment....Until we learn really to understand technology — how and when to apply it; how and when not to apply it — we shall never overcome the many, complex difficulties that beset us.” Kunkle, G. C. (1995). “New Challenge or the Past Revisited? The Office of Technology Assessment in Historical Context.” Technology in Society 17(2): 175-196.
and wide-ranging impacts. However, this does not necessarily reflect upon the ability of the evaluators, but rather the behavioral complexity and inherent non-predictability of the system (Dodder, Sussman et al. 2004). Many engineering systems can be described as complex adaptive systems, in which even simple interactions between individual elements can produce patterns at the system level that cannot be predicted from the behavior of those individual elements that make up the system—a characteristic described as emergence (Holland 1998). As discussed earlier, the difference between cause and effect (actions and impacts) can be spatial, temporal, and substantive. In implementing or deploying new technologies, a field test or pilot program may uncover some of the near-term and more direct impacts; however, the longer or even medium-term impacts of deploying new technologies at the system-wide level will not become evident until months, years or decades after full deployment. Perrow’s analysis of systems in *Normal Accidents* provides a number of examples of complex and tightly-coupled systems, where technologies and organizational routines interact in ways that can be catastrophic (Perrow 1984). The development of the automobile presents another example of the anticipated and unanticipated impacts of this technology on society. For example, the introduction of the automobile was expected to have the near-term impact of dealing with the problem of urban manure. However, as the automobile because more entrenched in society, the long-term impacts of sprawl, deterioration of the inner cities, and smog and its health impacts, would not become evident until years later.

### 4.4.2.2 Construction of Models and Facts

The view that the “facts will speak for themselves” is part of the rational-democratic model of public policy, according to which “facts, data, and information are neutral, and can settle conflicts” (Stone 1996, p 321). This scientific optimism pervades the common approach to policy analysis, which suggests that through better science, more research, data collection, improved models, and better communication of these results to decisionmakers, resolving uncertainties regarding technologies simply a matter of time. However, the constructivist critique, as expressed by observers such as Jasanoff, suggest that “facts are accepted as authoritative not necessarily because they can be empirically verified, but because they are validated through processes of informal negotiation and can be ranged into frameworks of shared assumptions and inferences” (Jasanoff 1987, p 195). In other words, this represents an explicit recognition that models and frameworks are an abstraction of reality, and may not necessarily be the correct or only abstraction.

### 4.4.2.3 Models and Methods in Multi-organizational Settings

The “social construction of facts”99 is also evident in the development of models when those models are employed in regulations or negotiations. Implicitly recognizing this element of social construction, some practitioners of IA have exhorted the community “to view models as tools to help understanding in the assessment, rather than as ultimate goals and end products of the

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analysis... giving up the view of models as ‘truth machines’” (Toth and Hizsnyik 1998). The extent to which models are often taken to be “truth machines” is unveiled when there is a clash of models investigating the same phenomenon. For example, in looking at long-range transport of ozone precursors, the European and U.S. predictive models used in assessment, although investigating the same physical phenomena, turned out to produce much different outcomes that could not be reconciled in the policy debate. This led to competing claims as to the credibility of the models, and critiques and counter-critiques of the European and U.S. models, and an eventual “agreement” by both sides to disagree (Keating and Farrell 2001). Within this paradigm, it should come as no surprise that “conflicts of opinion between well-informed experts [are] by no means exceptional” on issues of supposed “fact” (Freeman 1995, p viii). However, conflicts of opinion may also represent other interests at work.

4.4.2.4 Honesty

Finally, within the realm of evaluation and planning, there is also a concern about the extent to which “honest” evaluations are undertaken. In a short article with the provocative title of “When Planners Lie,” Wachs discusses this issue in the context of urban planning (Wachs 1989). Wachs addresses, with more sympathy than the title would suggest, the dual roles that analysts and planners must often play.

“On one hand, planners may see themselves as ‘scientists,’ who analyze data to discover the truth and to arrive at the best course of action. On the other hand, planners see themselves as ‘advocates,’ who use data and models to prove that a course of action preferred by a client or employer is the best choice in a given situation” (Wachs 1989, p 476-7).

Although Wachs’ analysis focuses on the planning stage (before a project), the lessons can also be applied to evaluation (after a project), although it could be argued that for political and organizational reasons of avoiding public failures, the pressure to demonstrate the positive outcomes of a project could be even higher. This reflects in part the often-cited phrase of Allison, that “Where you stand depends on where you sit.” However, in the later editions, this position was clarified to offer a softer version, suggesting that “where you stand ‘is substantially affected by’ where you sit...” but that the player may “resist or ignore the conditioning that arises from the person’s seat in government” (Allison and Zelikow 1999, p 307). Finally, by honesty, we do not necessarily mean outright lying or deliberate manipulation (although this may also happen), but as a call for:

“the critical need for producers and users of any IA products to open and conclude their presentations with clear statements about the assumptions and uncertainties in the methods, and not to overload the presentation with stand-alone, caveat-free, multi-decimal place tables or results that can be easily over-interpreted by uninformed uses” (Schneider 1997).

Assessment of the environmental impacts of new technologies faces several organizational and political challenges. While regulatory purposes often make it necessary to assess environmental impacts, organizations, by their nature, are not adept at objective analyses of the implications of their own programs. Regulatory oversight and external review can provide a quality control of
the quality of assessments, however, as might be suggested by the constructivist view, narrowing in on one accepted problem framing, or modeling approach, may blind organizations to the implicit assumptions and inferences that their models or analyses contain.

4.4.3 Adaptation

We will now look at the concept of adaptation to new information, as it relates to innovation and the deployment and adaptation of new technologies. While the above section describes attempts to assess the potential impacts that a technology may have, these represent only the ex ante evaluations. However, once implemented and in operation, there are also possibilities for ex post evaluations. In principal, these evaluations will more accurately describe and measure the actual outcomes of a particular technology deployment. Once innovations have been implemented, there are opportunities for detailed and realistic analysis of outcomes using measured data rather than projections and assumptions drawn from earlier projects or similar projects implemented in other areas. For newer technologies, ex post evaluations are particularly important, to assess to what extent the ex ante evaluations were actually accurate or not, and to better understand the tradeoffs and the unintended/unforeseen effects of the project or program. In theory, there are opportunities to adapt the project or program to take into account this new information, as well as to make changes to future projects and programs based upon the performance of earlier, similar efforts.

While it would seem straightforward to modify and improve projects based upon emerging information on their performance, this is not always the case in practice. Generally speaking, adaptation by public sector agencies will confront the same barriers discussed in the earlier section on barriers to innovation. Organizations – once their programs and projects, and the tasks and standard operating procedures to support them, are in place – are usually reluctant to change them, even in the presence of new information. In part, this reflects a general inertia characteristic of bureaucratic organizations (whether public or private sector). However, it also reflects the multiple goals and distributional considerations that are faced by public sector organizations. Changing an existing program or project may improve it in ways that may gratify some stakeholders who benefit from those adaptations. However, it may also create disgruntled stakeholders, who preferred the original form of the innovation.

Other scholars have addressed this topic of adaptation to information; however, by looking at legislators and regulatory agencies, not project- and program-implementing agencies. For example, Zuckerman compares evaluation and adaptation in U.S. regulatory policy for three cases - food safety, air pollution and financial services. He suggests that:

"[while] the political science literature gives inadequate consideration to the ability of government organizations to adapt to changing conditions and improve policy-making.... the conventional wisdom in the scientific community that more science directly leads to improved policy takes insufficient account of the organizational and political difficulties..." (Zuckerman 2001).

In theory, the emergence of new information, such as the information provided by a detailed ex post evaluation of an innovation, would lead to adaptation. However, according Zuckerman, that
is not always the case, at least in terms of policy and legislative adaptation. Furthermore, where adaptation does happen, the outcome is not necessarily beneficial. He concludes that more and better information is not the panacea to the problem of adaptation, but rather structural changes are needed to better use assessment and evaluation.

Golden offers a different perspective. Indeed, her model depends upon a process similar to that of Lindblom’s “muddling through” (Lindblom 1959; Golden 1997). Studying innovations in human services agencies, she highlighted the role of analysis in innovation, differentiating between the analysis done before the launch of an innovation, and the analysis that is undertaken after the innovation is in actual operation. In a logic similar to that of Lindblom (1959), she compares a “policy planning” model based upon extensive and careful analysis, and a “groping along” model of “rapid action modified by experience.” Favoring this later model, as a more accurate description of innovation in practice (at least for her sample of 17 innovations in human services agencies), she suggests that there is highly intensive use of information and continual adaptation to that information.

"After acting, [human service managers] cared intensely about the information to be gained from those actions, and they were able to carry their organizations with them in mulling over the information and in responding to it, over and over again. For them, operational experience provided the material for continuous innovation" (Golden 1997, p 172) (italics added).

This suggests a process of adaptive innovation, characteristic of the “ideal” case of technology management that we will describe below. The cases in the following chapters will be used to test to what extent ex ante analysis or ex post evaluation is indeed used to innovate with ITS for air quality purposes. We will consider not only information produced by the implementing agencies, but information produced by external reviewers (such as higher levels of government), universities, and research institutions, among others. For the case of information regarding the impacts of ITS, we will also examine whether information on air quality benefits, as opposed to information regarding more traditional transportation benefits of travel time savings, is also used to modify and adapt innovations.

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101 Golden (1997) represents an updated version of her 1990 article with the same title.
4.5 INTEGRATED INNOVATION, DEPLOYMENT AND ADAPTATION OF PUBLIC TECHNOLOGIES

4.5.1 Definition

We have discussed issues of innovation, cooperation, assessment and adaptation, focusing on innovation as the implementation of new technologies by public sector agencies. However, up until this point, we have reviewed the theories and concepts of innovation, cooperation, assessment and adaptation as relatively separate. In this section, we will tie together these concepts in our formulation of the desired outcome for the management of technology and its impacts in the public sector. This can be summarized as the following.

*Public sector organizations cooperate to adopt and use new technologies in support of multiple policy goals. This process of innovation is iterative, as agencies assess impacts and adapt technologies to new information on outcomes.*

According to this framework, cooperation between multiple agencies – for example, between technology promoters and regulators – results in the deployment of innovations that achieve the policy goals of all agencies involved. These are the so-called “win-win” outcomes. However, in this thesis we are looking specifically at “win-win” technology deployments in the public sector, with the added features of continuous assessment and adaptation.

We refer to this as Integrated Innovation, Deployment and Adaptation of Public Technologies (IIDAPT). The term integrated suggests the active pursuit of multiple public policy goals that pertain to more than one public sector agency. This may be through active involvement and cooperation of several (at least two) agencies in the design and deployment of a new technology, or the more unilateral initiative of one agency to support the organizational and policy goals of other agencies (in addition to their own goals), during the process of innovation and deployment. Deployment indicates that we are focusing only on technologies that actually reach the operational stage, not technology development, research or invention (although those may be activities leading up to deployment). We use the term innovation with two ideas in mind. First, there is innovation in the application of advanced technologies (such as ICT) to new sectors (such as transportation). Second, there is another layer of innovation when these advanced technologies (ICT), are applied to a new sector (transportation), in support of non-traditional goals (air quality). Therefore, innovation, as we are using it here, is a combination of technological innovation, with the adoption and adaptation of advanced technologies, and policy innovation, in using these technologies in novel ways for reaching additional policy goals. We also use the term adaptation to refer to the process of continual assessment of technologies and their impacts, using the information that is generated during the evaluation process to improve and modify the already implemented innovation, and/or designs for future deployments. Finally, we use the term public technologies to indicate that these are technologies deployed primarily by public sector organizations (although there may be additional cooperation and support from other organizations), and that the technologies are intended to provide public benefits or public goods. In the case of this research, those public benefits are mobility and accessibility and air quality.
Innovation, as discussed earlier, can occur through a combination of organizational, institutional and technological change. In this thesis, innovation can be not only technological (development, adoption and adaptation of technologies that are new to the public sector agencies), but also organizational (for example, the deployment of those technologies in support of goals beyond the regular missions and tasks of the implementing agency) and institutional (when it is done by creating new mechanisms for cooperation with other agencies) in nature. However, we also deliberately incorporate "technology" in our definition to indicate that this research focuses on innovations that include an important technological component, in contrast to other policy, legislative or regulatory innovations in the public sector.

The application of ITS technologies—advanced information and communications technologies, many of which originated in the defense sector—to the transportation sector is a technological innovation in that there are nontrivial adaptations of these technologies to the context of each agency and regional transportation system. In addition, when their use is broadened to incorporate issues of air quality, ITS deployments can be an organizational, as well as technological innovation. At the minimum, there is an organizational innovation when a traditional transportation agency uses a technology to advance policy goals (i.e. air quality improvements) that are largely external to their own agency's core mission. It can also, but is not always, a more advanced technological innovation if there is further adaptation of the physical system to improve air quality (i.e. changing the system design or operational parameters to further reduce emissions). For example, some of the energy and emissions ITS technologies defined and described in Chapter 2 would represent both organizational and technological innovations. Finally, institutional innovation also occurs when there are nontrivial changes to the relationships between organizations, in terms of planning, deploying or operating certain technologies. Institutional changes may be either a prerequisite condition to undertaking the technological innovation, a result of the technological innovation redefining the relationships between agencies, or, in many cases, both.

We further suggest that there is a scale of IIDAPT outcomes. High IIDAPT levels, for example, might reflect a more active involvement of various agencies and tighter integration of both mobility and air quality concerns. High IIDAPT would also reflect the use of more advanced technologies, or application of technologies in highly novel ways to support multiple policy goals. High quality evaluations and continuous adaptation of technologies to improve outcomes, would also be a characteristic of high IIDAPT. At the other end of the scale, low IIDAPT outcome would reflect minimal integration of air quality concerns into ITS deployments, sporadic assessment and little adaptation to new information, and the use of less advanced technologies. Our hypothesis is that levels of IIDAPT are influenced by certain conditions that promote or inhibit the adoption of new technologies in support of multiple policy goals.

IIDAPT is closely related to the idea of "win-win" outcomes. This involves overcoming what are typically perceived as trade-offs, such as the classic case of tradeoffs between economic competitiveness and environmental protection, or in the case of transportation, the tradeoffs between increased mobility and air quality. However, the advantage of the way we have conceptualized IIDAPT, is that it represents a scale of outcomes, which the concept of "win-win" outcomes cannot capture. Similar concepts have also been explored by researchers, who
have developed theories of “co-production” and “co-optimization” between technological advances and their impacts. We will discuss these concepts briefly, as they represent concepts similar to our definition of IIDAPT.

4.5.2 Relationship to Co-production and Co-optimization

Theories of environmental regulation have stressed the need for a shift from end-of-pipe pollution control to pollution prevention and clean technology (Schot 1992, pp 42-43). Looking at the relationship between government regulators and private industry, Ashford suggests:

“The challenge is how to use environmental regulation for win-win payoffs for co-optimizing growth, energy efficiency, environmental protection, worker safety, and consumer product safety” (Ashford 2000, p 15).

Described more broadly, the term co-optimization represents “the simultaneous achievement of a number of societal goals, rather than trading one off for another” (Ashford, Ayers et al. 1985; Ashford 2005, p 54). The concepts of so-called “win-win” situations and co-optimizing across variables that represent different societal values are also reflected in an approach referred to as Constructive Technology Assessment, developed primarily in Europe (Schot 1992; Rip, Misa et al. 1995). These authors contend that what is needed are “mechanisms and processes to facilitate societal learning about how to co-produce technology and its impacts, and how to achieve desirable outcomes” (Rip, Misa et al. 1995, p 3, italics added). While these authors might not agree that co-optimization and co-production are interchangeable terms, we consider these concepts to be close relatives in that they focus on a proactive approach that anticipates environmental (and other) impacts early in the process, and integrates them into the planning, design and implementation of new technologies.

The relevance of this approach is that it more explicitly recognizes the struggles within government (as well as between government and industry) reflecting what they refer to as the “two-track” approach of distinguishing between control/regulatory agencies and technology-promotional agencies, where government both supports the development of what are deemed to be “desirable” technologies, while regulating or punishing “undesirable” technologies (Rip, Misa et al. 1995, p 4). This is the issue of fragmentation and decentralization discussed earlier. For example, in a study of the design and implementation of a waste disposal site, the dilemma of the dual role played by planners was evident, as they were responsible for efficiently clearing away an abandoned waste site with polychlorinated biphenyl (PCB) contamination, while meeting legal requirements and addressing the demands of the public regarding the appropriate level of risk in the process (Herbold 1995, p 188). In this case, involvement of the public was the mechanism for controlling the negative impacts and risks. However, in many cases, these two roles are played by different public sector agencies – the so-called technology promoter and the controller/regulator. Here, the public demands for greater control of impacts were expressed through the regulating government agency.

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102 The literature on constructive technology assessment (CTA) has focused more on articulating the new paradigm of CTA and highlighting successful cases of this approach, rather than identifying the conditions under which a CTA-type process can and will occur.
This goal of co-production or co-optimization of the benefits and impacts of new technologies, requires assessment of the impacts, and incorporation of that knowledge into operational or design changes to the technological system. This suggests a process of continuous iteration in the development, adoption and adaptation of technologies and the evaluation of its performance and impacts. It also highlights the role of active assessment in the various stages of deployment. The concept of Constructive Technology Assessment (CTA) also suggests that assessment can be used as a vehicle for overcoming fragmentation between the technology-promoting and regulatory agencies. Therefore, CTA could be considered a subset of Integrated Innovation, Deployment and Adaptation of Public Technologies, with more focus on the role of assessment, and of integrating not only other agencies, but also stakeholders, more directly in the process of innovation.

4.5.3 Measuring IIDAPT

The literature reviewed in this chapter, pointed to four supporting activities for IIDAPT. These were cooperation, innovation, assessment and adaptation. We also suggested that there is a continuous scale of IIDAPT, from high IIDAPT levels, to possibly zero IIDAPT. Linking these two concepts, we propose that IIDAPT levels are determined by the levels of the four supporting activities: (a) levels of interagency cooperation, (b) levels of innovation in terms of the novelty of the technology/system or its application to new policy objectives, (c) quality and consistency of assessments of performance and impacts, and (d) levels of response to assessments, in terms of adapting technology deployments to improve outcomes for core policy objectives only, or for multiple policy objectives. By dividing the concept of IIDAPT into these four activities, shown in Table 4-1, we can more explicitly define a scale by which to measure IIDAPT in a concrete and reproducible manner.

Table 4-1 Qualitative Scale for Integrated Innovation, Deployment and Adaptation of Public Technologies

<table>
<thead>
<tr>
<th>Core Activities</th>
<th>Supporting Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooperation</td>
<td>Innovation</td>
</tr>
<tr>
<td><strong>High</strong></td>
<td>High level of novelty in the technology or its adaptation to multiple policy goals.</td>
</tr>
<tr>
<td><strong>Low</strong></td>
<td>Some novelty in the technology or its adaptation to multiple policy goals.</td>
</tr>
<tr>
<td><strong>None</strong></td>
<td>No cooperation.</td>
</tr>
</tbody>
</table>
It should be emphasized that this scale can be applied to each individual technology deployment or class of technologies deployments, as long as it is consistent across cases. We will later discuss how to “scale up” IIDAPT to the level of a metropolitan area.

While assessment and adaptation are supporting characteristics of IIDAPT, the minimum characteristics for whether an activity is even a low level of IIDAPT, is that it meets the core activity characteristics of: (1) indirect involvement, at the least, from other agencies when deploying the innovation, and (2) some novelty in either the technology itself or the manner in which it is use to address multiple policy goals. Therefore, the technology would have to meet at least the “low” level for both cooperation and innovation to be considered even low IIDAPT. For example, for the level of cooperation is not a function of the number of agencies involved, but how actively each agency participates with others. “Cooperation” can range from simply approving a deployment, providing funding for a deployment, to actively working on the design and/or operational aspects of a deployment. It can also include pressuring/persuading other agencies to incorporate additional policy objectives such as air quality for ITS. Supporting activities include assessment and adaptation, which can also rank as none, low or high.

Because this thesis represents a combination of theory development and theory testing on a limited number of cases, we are wary about full quantification of the variables at this stage, as it may conceal some of the phenomena we are hoping to gain insight into through the case study approach. However, in order to facilitate some comparison and aggregation for different ITS applications, we apply a simple numerical scale to the levels of “none,” “low,” and “high” for each of the four elements of IIDAPT. Because assessment and adaptation are supporting activities, they are counted as half of the points given to cooperation and innovation.

<table>
<thead>
<tr>
<th></th>
<th>Core Activities</th>
<th>Supporting Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cooperation</td>
<td>Innovation</td>
</tr>
<tr>
<td>High</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Low</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>None</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Assessment</th>
<th>Adaptation</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Low</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td>None</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

As noted above, this scale of IIDAPT would be applied on the basis of each individual technology. Indeed, there needs to be a substantial amount of information regarding the individual technology or system and the manner in which it was deployed and adapted, in order to assess where it lies on this scale of IIDAPT. However, for the purposes of this thesis – identifying and testing conditions which lead to lower or higher IIDAPT levels – we look at IIDAPT at the scale of the metropolitan region. The hypothesis is that there are conditions, which vary from city to city, that determine levels IIDAPT. The contribution of this thesis is to

103 As a hypothetical example, an ITS-air quality application with low cooperation (1), high innovation (2), high assessment (1) and low adaptation (0.5), would have a total of 4.5 on scale of 0 to 6, with 6 being the maximum level of IIDAPT possible. A score of 0 would not be IIDAPT.

104 For future studies addressing IIDAPT for other technologies, there may not be a need to “scale-up” from the level of individual technologies. However, we are interested in the factors that describe the differences between metropolitan areas, and their “success” in reaching high levels of IIDAPT for the case of ITS and air quality.
identify these conditions, based upon the theories reviewed above, and test them across a set of five in-depth case cities. This level of analysis enables us to examine some individual technologies that were deployed, but while placing their deployment within the context of a region’s overall transportation and air quality planning process. Therefore, we are looking for conditions that determine levels of IIDAPT across metropolitan areas.

For each city, we will attempt to identify a set of “representative” technologies (i.e., ITS applications that are used for the purposes of achieving both air quality and mobility goals in each city). We will define IIDAPT – innovating and adapting ITS technology for both mobility and air quality improvements – with the criteria that the deployments must have air quality as one of the policy objectives, as expressed through (1) funding eligibility requirements, (2) inclusion as a TCM in an implementation plan for air quality (or other plan, such as an Early Action Compact), (3) inclusion in other lists of voluntary measures for mobile emissions reductions, or (4) inclusion in a region’s core air quality programs, such as those managed by MPOs or state environmental agencies. We will rank these applications on the scale of IIDAPT developed above (see Table 4-1 and Table 4-2). Some cities may have only one application that meets our criteria for IIDAPT, while other cities may have many applications across several different modes. However, by looking at the level of IIDAPT across different ITS application areas, we can also determine the range of use of ITS for air quality. If there are projects spanning many of these categories, it indicates that ITS is used for the purposes of air quality for many different facets of the metropolitan transportation system – arterial streets, freeways, transit systems, HOV lanes, ridesharing programs, and so on. Table 4-3 illustrates the process of scaling up from IIDAPT levels for individual ITS technologies (again, as described above in Table 4-1 and Table 4-2), to two measures of IIDAPT that indicates the average level and range of IIDAPT for each metropolitan area.

Table 4-3 Scaling up from technology-specific to metropolitan-area IIDAPT levels

<table>
<thead>
<tr>
<th>ITS application areas</th>
<th>Houston</th>
<th>Los Angeles</th>
<th>Metropolitan Area</th>
<th>Orlando</th>
<th>Tulsa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arterial traffic flow improvements</td>
<td>#</td>
<td>#</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Freeway management strategies</td>
<td>#</td>
<td>#</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Freeway traveler information</td>
<td>#</td>
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<td></td>
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<tr>
<td>Transit information</td>
<td>#</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Multi-modal information</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transit operational improvements</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transit fare payment systems</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rideshare support</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Demand management/pricing</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other applications</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average level (0-6)</td>
<td>Average IIDAPT levels</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>Range (0-10)</td>
<td>Number of IIDAPT applications</td>
<td>...</td>
<td>...</td>
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<td>...</td>
</tr>
</tbody>
</table>
The first measure, average level, takes the average of only those technologies considered to be IIDAPT. However, it is also important to understand the range of ITS applications used for air quality purposes in the metropolitan level. There are ten categories of ITS application areas: three freeway and arterial ITS, three transit ITS, multi-modal traveler information, rideshare support, demand management/pricing, and other applications. Having one application in each of the ten rows of Table 4-3, would indicate the maximum range of applications, and more generally, a balance across modes in the use of ITS for air quality.

However, one cannot judge from this table alone whether there are one or many deployments in each of the categories (e.g., one advanced traffic signalization project to reduce emissions, or fifty such projects). Therefore, we need some measure of the number of ITS-air quality projects, and how they compare to other transportation-related projects for air quality. To operationalize a measure of the frequency or intensity of use of ITS for emission reductions, we will look at the percentage of ITS-related projects that are included in metropolitan air quality plans and programs (as transportation control measures or other similar but voluntary measures). While this might not capture the full universe of IIDAPT efforts in a metropolitan region, because they are included in air quality and transportation plans and programs, they are officially recognized as having legitimate air quality benefits by the local and state agencies. We also consider another measure, which is the use of CMAQ funding, since projects are required to have emissions benefits (and to document those reductions) in order to be considered eligible for this funding category. For both of these measures, where the data permits, we will look both at the number of projects (number of ITS projects out of all TCMs and CMAQ projects), and the percentage of funding (the amount of funding for ITS projects out of all TCMs and CMAQ funding). This measure of IIDAPT intensity could therefore range, theoretically, from 0% of a metropolitan area’s transportation-based emission reductions measures to 100% of those measures.

We have now developed several quantitative measures for IIDAPT, specifically for the case of ITS deployments for air quality purposes (see Table 4-4). The first two measures are the average level and diversity of IIDAPT. The first measure captures the average level of innovation, cooperation, assessment and adaptation (as described in Table 4-1 and Table 4-2), while the second measure reflects the range or applications and modal variation. The third measure takes a different approach, looking at the intensity of IIDAPT as a measure for transportation-based emission reductions (i.e. of all the options to improve air quality, how frequently ITS is employed as an emission reduction measure).

<table>
<thead>
<tr>
<th>Metropolitan Area</th>
<th>IIDAPT measures</th>
<th>Houston</th>
<th>Los Angeles</th>
<th>Boston</th>
<th>Orlando</th>
<th>Tulsa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average level</td>
<td>0-6</td>
<td>0-6</td>
<td>0-6</td>
<td>0-6</td>
<td>0-6</td>
<td>0-6</td>
</tr>
<tr>
<td>Range</td>
<td>0-10</td>
<td>0-10</td>
<td>0-10</td>
<td>0-10</td>
<td>0-10</td>
<td>0-10</td>
</tr>
<tr>
<td>Intensity</td>
<td>0-100%</td>
<td>0-100%</td>
<td>0-100%</td>
<td>0-100%</td>
<td>0-100%</td>
<td>0-100%</td>
</tr>
</tbody>
</table>

However, as will be discussed in Chapter 6, for the cross-case comparison, we will use the percentage of ITS or ITS-enhanced projects out of all transportation control measures (TCMs) in each metropolitan area’s most recent air quality plan.
These measures will be used *in support* of the qualitative description of actual outcomes for IIDAPT for the five case study cities. We will not rely entirely on these measures, but will use them in conjunction with the qualitative description of IIDAPT efforts in each city. Because this research has a theory-building function as well, full reliance on quantified measures, at this point, may obscure critical issues and connections we are attempting to understand.

We have outlined how IIDAPT can be described and measured; first, at the level of individual technologies, and second, at the metropolitan level for many technologies. The case study work, in the next chapter, will then be used as a basis to describe and measure IIDAPT in five cities.

We now turn to the other side of the equation, which are the conditions that, according to the theory, should predict both the occurrence, level and intensity of IIDAPT. We will then show in Figure 4-1 how these conditions relate to the IIDAPT outcomes.

### 4.5.4 A Theory of IIDAPT

Now that we have formulated the concept of Integrated Innovation, Deployment and Adaptation of Public Technologies (IIDAPT) and described a process for measuring IIDAPT levels, we will discuss the conditions that, we hypothesize, contribute to higher or lower levels of IIDAPT. Four fundamental issues were identified and discussed in previous sections:

- barriers to innovation and experimentation inherent in public sector organizations,
- cooperation and overcoming fragmentation between "promoters" and "regulators" of technologies in the public sector, and
- difficulties of technology assessment in the public sector, and
- difficulties of public sector agencies adapting to new and better information, such as the information generated by assessments and evaluations.

Having reviewed the theories regarding innovation, cooperation, assessment and adaptation, we will draw upon those ideas to develop and advance seven propositions. These are the *conditions which we hypothesize will contribute to higher or lower levels of IIDAPT* in a metropolitan area for ITS and air quality. The first four propositions deal most directly with the conditions for innovation, although proposition three also deals with the capacity to undertake assessments. Propositions five and six address the conditions for cooperation and overcoming interagency fragmentation. The final proposition addresses the conditions that will support higher levels of adaptation. However, as will be illustrated in Figure 4-1, there are also important connections between these conditions.

The seven conditions represents a comprehensive, although not necessarily exclusive list of the conditions that influence the levels of Integrated Innovation, Deployment and Adaptation of Public Technologies. Drawing from the theories reviewed above, we have identified these conditions as important factors in enabling innovation and cooperation, as well as in undertaking assessments and using that information to adapt. However, this is an exploratory analysis. While we will test the five case study cities against the seven conditions developed here, the case
studies will also be used to possibly highlight other factors and conditions — either not incorporated in this theoretical framework, or previously overlooked by the literature — that seem to be important factors driving IIDAPT. The analysis may also serve to determine which conditions are not important determinants IIDAPT levels. Thus, the cases will not only test the theory, but allow us to further refine it.

Here, we will present the propositions related to the conditions that determine IIDAPT levels. We will then test these conditions against the five case study cities in Chapter 6.

4.5.4.1 Conditions for IIDAPT

Proposition 1: Public sector organizations will innovate in response to changes in the external environment, and the level of innovation will be relative to the severity of the problem.

The severity of the problem an agency faces, in many cases, can be objectively defined and sometimes measured quantitatively — traffic congestion levels, crime statistics, student dropout rates, etcetera. However, as it relates to the organization, the “problem” is defined as to what extent it creates dissatisfaction on the part of the agency, legislators, higher levels of government, and the public. It represents the mismatch between agencies’ current tasks, standard operating procedures, and missions, and the problems they are mandated to address. Generally speaking, organizations will not have pressures to innovate as long as their tasks, mission and standard operating procedure are adequate, but once they are challenged, they will be pressured to seek new solutions. For the case of local and state agency innovation, this can especially be driven by changes at the federal level, which may tighten regulation of the current tasks carried out by the agencies, or mandate innovative approaches to deal with problems.

Proposition 2: The level of an agency’s internal resources, in terms of funding, staffing levels, and education and training of staff, increases the capacity to adopt and deploy technological innovations.

Both the size of an agency, the number of staff working full time on a particular problem area, and the education and training of that staff are important factors in the ability to innovate. In particular, with technological innovations, the “in-house” technical expertise and experience are critical for effectively deploying and adapting new technologies. Agency funding is another key determinant of the possibilities for innovation, both in terms of overall agency funding, and the level of funding allocated to certain program areas, as discussed in the next proposition.

Prior experience with technological innovation may also be a component of internal resources, having developed the expertise and tacit knowledge required to innovate technologically. Technological innovation may also be a triggering device for more fundamental organizational and advanced technological change; thus prior experience with innovation will increase levels of IIDAPT. While technologies may be adopted as a simple tool for efficiency gains in existing operations and tasks, continued use of a new technology may provide the impetus and opportunity for deeper change. As technologies are incorporated into an organization’s repertoire of capabilities and tasks, they can create possibilities for organizational change and
innovation. Therefore, agencies are more likely to achieve higher levels of IIDAPT – which requires not only innovation, but coordination with other agencies and assessment of its impacts – if they already have a solid base of experience with technological innovation. This represents a form of “path dependence” of technological development and innovation, where early successes or failures in deployment will help determine the path for the future direction of innovation. This suggests that across the cases, individual agencies with more experience with innovation, will tend to be more likely to innovate again.

An agency’s internal resources – staffing levels, funding, education and training of the staff – would not only lead to greater innovation, but would likely increase the amount of assessment that is undertaken.

**Proposition 3:** Dedicated resources to specific categories of programs or project will lead to more innovation in that area.

In addition to the general funding categories available to an agency, the federal government can also provide “carrots” or targeted incentives for adopting and implementing certain types of programs or projects. These incentives will often come with conditions for their use and for which types of projects are considered eligible. Or, agencies can create their own “set-asides” of funding amounts dedicated to specific areas. Agencies with access to a larger “pool” of “slack” resources open to particular categories of non-traditional activities, will be more likely to develop innovative approaches, than if those funds had to compete with a broader range of more traditional activities. As a corollary, if the requirements for accessing those funding categories requires addressing multiple policy goals, beyond the core mission of the implementing agency, then the probability for integrated innovation will increase.

**Proposition 4:** Lower cost innovations will be more likely to be deployed.

While not specifically discussed in the theory, it is reasonable to further suggest that low-cost innovations will be easier to deploy, as they presumably do not overly strain the resource levels of agencies. Sapat, for example, suggested that resource-poor agencies might innovate to create resources for themselves. We could extend this concept to suggest that agencies may also innovate more frequently with less expensive technologies. In addition, failure of a lower-cost innovation would not have the same negative repercussions with elected officials or the public, compared to the situation when this “experimentation” were to be undertaken at a much greater cost that would be more visible to the public. Therefore, agencies might be more willing to try using low-cost alternatives.

**Proposition 5:** Cooperation between agencies is more likely if there are perceived mutual benefits to be gained from the innovation.

Mutual benefits can be defined in several ways. First, mutual benefits can represent the outcome of addressing natural or created interdependencies between organizations in ways that are acceptable to each organization. Interdependencies can be the result of overlapping jurisdictions and problem domains, or can be created by higher levels of government. The goals of
environmental agencies "naturally" depend on what the transportation agencies do – decisions on road building can bring more cars, congestion, and emissions. However, the local and state transportation agencies do not "naturally" depend on the state and local environmental agencies, unless there are regulatory levers like the conformity requirements, created by the federal government. Conformity links the ability of transportation agencies to access funding or implement plans and programs, to whether they meet environmental and air quality goals, therefore creating a new interdependency. For example, returning to Lindblom’s idea of the process of mutual adjustment, mutual benefits can be, at the very minimum, simply avoiding or ceasing activities that have a negative impact on the other agencies.\textsuperscript{106} If there are strong interdependencies between the agencies, the possibilities for mutual benefits from cooperation increase. If a technology, such as ITS, can generate both air quality benefits and congestion mitigation and mobility benefits, there would be mutual benefits from cooperation between air quality agencies and transportation agencies.

Unfortunately, the above description represents mutual benefits in an overly superficial manner, defining mutual benefits according to the organizational mission or stated policy goals of public sector organizations. At a deeper level, mutual benefits must reflect actions that can advance the interests of the organizations. We will return to this idea frequently in later chapters.

\textit{Proposition 6: The likelihood of integrated innovation falls as the number of organizations with a stake or role in the innovation increases.}

As the number of agencies – whose interests are directly or indirectly affected by the implementation of an innovation – grows, the probability of successfully carrying out that innovation decreases. To begin with, the complexity of joint action increases the opportunities for failure to occur at one or another decision point, whether in terms of funding, approval, implementation, or operation. In addition, looking at multi-agency cooperation from a different perspective, one can also suggest that cooperation between a smaller number of players is easier, because the opportunities for free-riding are diminished.\textsuperscript{107} As the number of actors working toward common policy goals increases, individual organizations may feel less pressure to contribute than if working in a more closed context where there is better information and enforcement of the contributions of each individual organization.

\textit{Proposition 7: The availability of new and better information will lead to adaptation of programs and projects to improve outcomes.}

The conventional wisdom within the technical and scientific community is that better and more information will lead to adaptation and modification of existing programs to improve outcomes. Some scholars, such as Zuckerman, have found that that is not necessarily the case, at least in

\textsuperscript{106} Although seemingly straightforward, simply removing contradictions between different policies, carried out by agencies from different sectors, is highly difficult to do in practice.

\textsuperscript{107} The “free-rider problem” represents the attempts of individuals, organizations, countries, etc., to rely on the efforts or investments of others to provide a public or collective good, and then reap the benefits that that public good brings to all, assuming that they cannot be excluded from enjoying the public good. The outcome of the “free-rider problem” is under-provision of public goods.
terms of regulatory policy. On the other hand, scholars looking at innovations at the state and local levels, such as Golden and Behn, have found agencies and their managers to have a bias toward “rich information” regarding innovations and their outcomes. However, for the case of IIDAPT, outcomes are more difficult to define. We are looking at innovations with multiple policy goals and outcomes, meaning that an innovation may be successful according to some objectives, while perhaps being even detrimental according to other objectives. Therefore, the cases should be analyzed for how different information sets, analyzing different outcomes, are used. While information on some outcomes of a technology may be intensively used, information on other outcomes may be disregarded.

Assessment of technologies will generally have a mixed role. In some cases it may be used to justify or provide additional support to projects, or establish eligibility for funding. In other cases, it may be used in an effort to reduce the uncertainty about the impacts of technologies. Among organizations facing similar issues, it can also serve to diffuse ideas, experiences, best practices, and innovations. In many cases, assessments and evaluations are simply to fulfill reporting requirements. Determining whether evaluations are “honest” appraisals of outcomes or advocacy or justification for “favored” projects and programs, will be difficult. Looking at the quality of the assessment used, the rigor and transparency with which the assessment is done, and whether there are systematic biases created by the methodologies used, can provide some evidence. Yet, without a full “insider’s knowledge” of the process, it is nearly impossible to ascertain the true intent behind an assessment.

That said, in the absence of explicitly or tacitly accepted methodologies for assessing and evaluating the impacts of technological innovations, it is difficult to produce and incorporate new information into the design of future technology deployments involving multiple agencies. Indeed, the lack of widely accepted assessment approaches may, in some cases, actually hinder the process of Integrated Innovation, Deployment and Adaptation of Public Technologies, if the beneficial outcomes of these innovations and “experiments” cannot be demonstrated in a way that is convincing to all partners involved. Yet, “agreement” or “consensus” on modeling approaches does not necessarily mean that those modeling approaches are the most accurate or reliable means for arriving at the “truth.” Indeed, it is possible to agree on a sub-optimal or inferior approach (from the scientific/technical perspective) or an approach that ignores critical uncertainties, in attempting to find a methodology that suits the needs of all agencies.

Furthermore, innovation and assessment will more likely occur if it can be oriented toward short-term impacts, because assessments will generally perform better in evaluating short-term impacts rather than long-term impacts. As noted earlier, there is a general phenomenon of myopia in the assessment of technologies and their impacts. While short-term impacts can be evaluated with relative certainty, the long-term repercussions, because they cannot be explicitly modeled, will often be ignored or downplayed. Furthermore, the preference for organizations and politicians to show results of innovations sooner rather than later, will further amplify this focus on the concrete, short-term benefits, even if at the expense of more serious (but less uncertain) long-term consequences. Therefore, across the cases, we are likely to see a trend of directing assessments, innovations and adaptation, in response to more short-term impacts.
We will attempt to test whether more and newer information leads to adaptation of innovations. This information can be generated: (a) internally by the agencies themselves, (b) by consultants under contract to the agencies, (c) from reviews undertaken by higher-level agencies such as the FHWA, or (d) by universities, research institutes or other organizations under contract to agencies or undertaking the research independently. We will consider all of this information as relevant. Yet, as described above, it may be used in different ways by the innovation-implementing agencies.

4.5.4.2 Relationship between Conditions and IIDAPT outcomes

We have described seven conditions for IIDAPT. These conditions affect the level of cooperation, innovation, assessment and adaptation, which together determine the overall level of IIDAPT. However, there are also important interconnections between the conditions themselves, as mentioned above. These connections are illustrated in Figure 4-1. While the solid lines are the relationships already described by the theory, for comprehensiveness, we also describe below the secondary links between conditions (shown as dotted lines in Figure 4-1).

Reviewing Figure 4-1 from left to right, a larger number of agencies or organizations involved in IIDAPT can have two effects, in addition to the direct effect on cooperation. First, as the number of agencies involved grows, the possibility for finding mutual benefits that are acceptable to all, becomes smaller. Each agency brings their set of policy preferences and goals, meaning that the potential for conflicts between those goals also increases.

![Figure 4-1 Relationship between seven conditions and IIDAPT](image)

Problem severity, as described earlier, is a relatively straightforward condition; it provides both the need and motivation to innovate. This is the direct link from problem severity to innovation. Moreover, problem severity can also lead agencies, elected officials, or higher-level government agencies to allocate additional resources to this problem area. This pool of dedicated resources available to agencies can create a resource for enabling needed innovation. However, it can also
become another source of mutual benefits. This series of links from problem severity to dedicated resources to the problem to mutual benefits can lead to the creation of somewhat perverse incentives. Rather than mutual benefits deriving from the beneficial outcomes that certain innovations can bring to agencies and society by addressing critical problems, the mutual benefits become embodied in the dedicated resources that are created to solve those problems. Therefore, the search for innovations may be motivated not by the need to address an important problem, but how best to access the funding pool created to address that problem.

Perceptions of mutual benefits can also be affected by the generation of new information, which may better clarify the nature of those "mutual benefits. This influence can either be positive or negative. New information can either reinforce original agency attitudes regarding the so-called "win-win" possibilities from certain technology deployments. However, new information can also highlight potential conflicts and difficulties in actual meeting the multiple policy goals and agency objectives that those technology deployments were intended to address. New information can therefore change the perceptions of individual agencies regarding what they stand to gain, or even possibly lose, from a particular innovation. So, new information can alter the perceptions of mutual benefits, and thus the possibilities for successful cooperation.

These relationships clearly make the process of operationalizing and testing these conditions difficult. However, we argue that by using the case study methodology, we can look closely at these interconnections as well, and determine to what extent they are important or not.

4.5.4.3 Testing the Theoretical Structure

We have reviewed how to describe and measure actual IIDAPT outcomes, and then outlined seven theoretical conditions that influence these outcomes. The next step is to test how well the theoretical structure, shown in Figure 4-1, performs when comparing "predicted" to "measured" IIDAPT levels, as determined through detailed case study work. Basically, we will compare what the theory "predicts" the IIDAPT levels would be – based upon the seven conditions – to actual IIDAPT levels.
As illustrated in Table 4-5, we will qualitatively compare predicted to actual IIDAPT for each of the case study cities, in order to see to what extent the two descriptions concur or differ. This will both test how well the theoretical framework we have developed performs, and identify areas for further refinement of the theory. Because the seven conditions can be described only through a combination of qualitative and quantitative data, the predicted outcomes will necessarily be qualitative descriptions based upon those conditions. The theory reviewed in this chapter, and summarized in the propositions, will be used to make a qualitative prediction of IIDAPT based upon the seven conditions (the solid lines in Figure 4-1).

However, because the actual outcomes are based on deployments identified in the case study work, we can introduce some additional rigor into that measurement, and quantify IIDAPT levels (as described in Table 4-2 through Table 4-4). However, these quantitative measures will support the overarching qualitative description of IIDAPT. This qualitative description is important to ensure that we are not excluding pertinent information that may be incorporated into future improvements to the theory. While Table 4-5 summarizes how the final comparison will be made across the cases, Figure 4-2 diagrams the full analytical process for using the case study material to derive measures for both actual IIDAPT levels and the conditions that influence IIDAPT. It also highlights the process of scaling up from measuring IIDAPT at the level of an individual technology deployment, to the metropolitan level.\(^\text{108}\)

\(^{108}\) For this research, we are interested in trends at the metropolitan level, and explaining the differences between U.S. cities. This is because ITS and air quality are necessarily a metropolitan or regional issue. However, this scaling-up process to the metropolitan level may not be a necessary step when looking at other technologies/sectors with more localized impacts.
Figure 4-2 Process for measuring IIDAPT conditions and outcomes

Case studies for five U.S. metropolitan areas

Qualitatively describe “representative” IIDAPT.
See Table 4-1

Translate description of IIDAPT into numerical ranking
See Table 4-2

Scale up measure of IIDAPT from representative technologies to metropolitan level
See Table 4-3

Actual IIDAPT outcomes for each case
Detailed qualitative description supported by three quantitative measures

Average level of IIDAPT
Range of IIDAPT

Intensity of IIDAPT

Comparison of “actual” and “predicted” IIDAPT outcomes. See Table 4-5.

Predicted levels of IIDAPT
Described qualitatively based on seven conditions below

IIDAPT Framework
Theories of cooperation, innovation, assessment and adaptation. Based on literature in Ch 4.
See Figure 4-1.
Because the case study work has been used as a basis to measure IIDAPT outcomes (our dependent variable), and to measure the conditions that determine those outcomes (our independent variable), those measures must be produced in a rigorous and reproducible manner. For this reason, we have quantified the measures of actual IIDAPT outcomes to the extent possible, and will also partially quantify the seven conditions (with the exception of those conditions that are not amenable to quantification in an accurate and reasonable manner). Although the author undertook the case study research that produced both the measures for both outcomes and conditions, we use clear measures and descriptions of each that can be independently confirmed or contested by other researchers. By following the more rigorous analytical process summarized in Figure 4-2, we will be transparent about the steps used to described the conditions, the predicted IIDAPT levels, and the actual IIDAPT levels, therefore supporting the validity of the results and conclusions of this thesis.

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109 This research could be confirmed or contested either by reinterpreting the information provided by the author in the full case study descriptions in Chapter 5 and actual calculations of IIDAPT levels in Appendix E, or introduce additional information not previously considered. This could be used to challenge the descriptions and measures of both the actual outcomes and conditions. In terms of the determining the validity of the theoretical framework developed here, this could be confirmed or contested by introducing new theory from the literature, or applying the theoretical framework to additional cases.
4.6 SUMMARY

In the following chapters, we will test the conditions that we hypothesize contribute to higher or lower levels of Integrated Innovation, Deployment and Adaptation of Public Technologies (IIDAPT). We have reviewed and synthesized a large body of literature from political science, public administration, organizational theory into three areas – innovation in government, cooperation for multiple policy benefits, and assessment and adaptation of new technologies. We then used this literature to identify seven conditions: (1) problem severity, (2) internal resources, (3) dedicated resources, (4) mutual benefits, (5) cost, (6) number of agencies, and (7) new information. The proposed linkages between IIDAPT and the conditions that influence it have been described in detail in Figure 4-1. We have also developed a process for describing and measuring actual IIDAPT levels in Figure 4-2.

In the section on the appropriateness of the case study approach, we have described some of the theoretical contributions, in terms of theory building and testing. However, it is also useful to describe some of the more practical contributions we hope to make through this research. The objective of this research is to identify certain conditions that may inhibit or support IIDAPT. This has an important contribution to practice, as it can provide guidance to public sector agencies wishing to undertake IIDAPT, highlighting what conditions can increase the levels of IIDAPT that are possible. It can also show where IIDAPT may be unlikely to occur, and where it would be necessary to change those conditions. By applying and testing the conditions to the case studies, we also hope to identify which conditions can, in fact, be changed through policy interventions, and what types of changes seem most effective.

After Chapter 6, we will take the next step of applying this framework to evaluate its relevance and usefulness to informing policy. In Chapter 7, we will apply the results of the five US case study cities to a non-US context – the case of ITS and air quality in the Mexico City Metropolitan Area. The purpose will be to assess the possibilities for undertaking IIDAPT in Mexico City, based upon our theoretical framework, and recommend possible changes to create more favorable conditions for IIDAPT to occur. Given the enormous transportation and air quality challenges Mexico City is facing, and the fact that public sector agencies are beginning to use ITS more intensively in traffic and transit management, this research could provide timely advice regarding ways to leverage ITS for both air quality and mobility improvements. While we choose the same technology and issue domain – ITS and air quality – we will apply it to a very different geographic, organizational, and institutional context, where the seven conditions should vary substantially.

We will now turn to Chapter 5, where we review five case study cities in order to assess to what extent metropolitan areas have been able to overcome the barriers to producing “win-win” situations, in which the mobility benefits and air quality impacts of Intelligent Transportation Systems are actually co-produced. This chapter will provide the broader context for transportation and air quality planning in each city, and introduce the data that will be used to describe and measure IIDAPT outcomes. Then, in Chapter 6, we will apply theoretical framework described here and summarized in Table 4-5, in order to test the relationships between our seven conditions and outcomes for IIDAPT.
CHAPTER 5. U.S. CASE STUDIES IN ITS AND AIR QUALITY
5.1 INTRODUCTION

The hypothesis of this thesis is that there are identifiable conditions, varying from city to city, that determine what levels of Integrated Innovation, Deployment and Adaptation of Public Technologies (IIDAPT) can and will occur for ITS and air quality at the metropolitan level. One of the key contributions of this thesis is to identify a set of possible conditions (Chapter 4) and test these conditions for a sample of cities (Chapter 6). This current chapter has the primary purpose of showing the data used in the case selection process, and providing the information and background on the cases that will be necessary for testing them for the IIDAPT framework.

Five cities were chosen and analyzed using a combination of site visits with personal interviews, reviews of transportation and air quality plans and programs, and various secondary analyses from both the inside players and outside observers, ranging from program evaluations to press articles. The use of the case study format is considered appropriate for this research, because of the number of conditions we are testing (seven), the possibility for complex interactions between those conditions, and the difficulties in fully quantifying the conditions. As noted by Krathwohl, case studies are “ideal for illustrating the complexity of causation” (Krathwohl 1997). We chose five US cities through a process of “purposive sampling,” rather than taking a random sample of all US metropolitan areas (from the 78 total metropolitan areas for which aggregate data was available).

The structure of the chapter is as follows. First, we describe the indicators used to select the five case study cities used to test our IIDAPT framework (Section 5.2). Second, we will explain the case selection process and discuss the general approach used for the fieldwork (Section 5.3). Third, we provide the background information on each of the five case cities (Sections 5.4 to 5.8), that will be used in the testing of the cases in Chapter 6. We divide the case descriptions into four main parts: (1) general background, (2) recent history of air quality management and control of mobile source emissions, (3) ITS deployment trends, and (4) linkages between ITS technologies and air quality management strategies.
5.2 INDICATORS FOR ITS DEPLOYMENT AND AIR QUALITY LEVELS

Before moving into the individual case studies, we will first explore the data on ITS and air quality for 78 medium-large metropolitan areas in the US, and discuss both its general implications, and how this data was used to select case studies. The metropolitan areas used in the analysis are the 78 medium-large metropolitan areas covered in the ITS Deployment Tracking database, which will be described below.

5.2.1 Air Quality

For these 78 metropolitan areas, the most recent ozone non-attainment classification was used as an indicator of air quality. From a public health standpoint, using the ozone non-attainment level does not necessarily reflect the degree of risk from air pollution, since it only focuses on one of the criteria pollutants, and does not include other air pollution risks such as fine particulates (PM$_{2.5}$) and air toxics. A more comprehensive indicator for public health purposes would be the Air Quality Index (AQI) which integrates measurements of five of the six criteria pollutants (excluding lead) into a single indicator, where an AQI greater than 100 means that at least one pollutant was exceeded for the day (U.S. Environmental Protection Agency 2004). Since our interest lies in the institutional and organizational impact of more stringent air quality regulations, rather than air quality as such, the 1-hour ozone non-attainment classification provides a good indicator for the severity of the air quality problem from the regulatory standpoint.

Until the 1990 Clean Air Act Amendments, an area was declared in either attainment or non-attainment for air quality standards. The 1990 CAAA differentiated areas according to the level of severity of their air quality problem, which would then determine the schedule and deadline for bringing the area into attainment. The ozone non-attainment designations are determined by the EPA according to the “design value” for 1-hour ozone, where the design value represents the fourth-highest monitored value for three complete years of monitoring. This method allows for one “exceedance” per year. Therefore, an area is determined to meet the NAAQS, and thus be in attainment if the ozone 1-hour standard is not exceeded more than one day a year on average for three years. The fourth exceedance within a three-year period triggers non-attainment status, and the design value is based on that measure.\textsuperscript{10}

Table 5-1 1-hour ozone classifications and attainment dates

<table>
<thead>
<tr>
<th>Nonattainment Classification</th>
<th>Design Value</th>
<th>Must meet standards by:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extreme</td>
<td>0.280 ppm and above</td>
<td>2010</td>
</tr>
<tr>
<td>Severe-17</td>
<td>0.190 up to 0.280 ppm</td>
<td>2007</td>
</tr>
<tr>
<td>Severe-15</td>
<td>0.180 up to 0.190 ppm</td>
<td>2005</td>
</tr>
<tr>
<td>Serious</td>
<td>0.160 up to 0.180 ppm</td>
<td>1999</td>
</tr>
<tr>
<td>Moderate</td>
<td>0.138 up to 0.160 ppm</td>
<td>1996</td>
</tr>
<tr>
<td>Marginal</td>
<td>0.121 up to 0.138 ppm</td>
<td>1993</td>
</tr>
<tr>
<td>Submarginal 111</td>
<td>less than 0.121 ppm</td>
<td></td>
</tr>
<tr>
<td>&amp; Section 185A 112</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: 1990 CAAA, Section 181, Table 1
(U.S. Environmental Protection Agency 1991)

As our indicator for the severity of the air quality problem, we will use the non-attainment classifications established in the Congressional Federal Register on November 6, 1991, although this includes some areas that have since returned to attainment status (U.S. Environmental Protection Agency 1991; U.S. Environmental Protection Agency 2004). Some areas have returned to attainment more recently, while some were re-designated as attainment within a few years after the 1991 designations. For example, St. Louis, Birmingham, San Diego, Denver, Louisville and Pittsburgh have all been re-designated to attainment status within the past few years. On the other hand, the State of Ohio, with the exception of Cincinnati, was able to bring its marginal and moderate 1-hour ozone metropolitan areas (5 in total) back to attainment by 1996. Nevertheless, the majority of the non-attainment areas used in this analysis (32 of 56) were non-attainment for at least 10 years between 1992 and 2004. Furthermore, as seen in Figure 5-1, no “severe” or “extreme” areas, and only two “serious” non-attainment areas, have been re-designated to attainment; those areas with the most movement from nonattainment to attainment status are in the categories of submarginal, marginal, and moderate.

111 According to the EPA’s definition: “Kansas City was the only area classified submarginal, but it has been re-designated attainment. This category includes areas that violate the ozone standard and have a design value of less than 0.121 parts per million. This occurs when there is not a complete set of data so that the estimated design value is higher than the ozone standard exceedance rate of 1.0 per year even though the estimated design value is less than the level of the standard.”

112 These areas, referring to Section 185A of the 1990 CAAA, are defined as the following: “an area designated as an ozone non-attainment area as of the date of enactment of the Clean Air Act Amendments of 1990 has not violated the national primary ambient air quality standard for ozone for the 36-month period commencing on January 1, 1987, and ending on December 31, 1989.”
### Figure 5-1 Re-designated areas by level of non-attainment

<table>
<thead>
<tr>
<th>Classification</th>
<th># Areas</th>
<th>Redesignated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Attainment</td>
<td>22</td>
<td>N/A</td>
</tr>
<tr>
<td>Submarginal/Section 185A</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Marginal</td>
<td>14</td>
<td>9</td>
</tr>
<tr>
<td>Moderate</td>
<td>17</td>
<td>16</td>
</tr>
<tr>
<td>Serious</td>
<td>9</td>
<td>2</td>
</tr>
<tr>
<td>Severe-15</td>
<td>6</td>
<td>0</td>
</tr>
<tr>
<td>Severe-17</td>
<td>4</td>
<td>0</td>
</tr>
<tr>
<td>Extreme</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>78</strong></td>
<td><strong>31</strong></td>
</tr>
</tbody>
</table>

*Source: (U.S. Environmental Protection Agency 2004)*

### 5.2.2 ITS Deployment

Our other variable of interest is the level or intensity of ITS deployment in a metropolitan area. This variable represents the extent to which the elements in a metropolitan transportation system – including freeways, arterial streets, transit, and even individual drivers – are actively “managed” using real-time information on the status of the transportation system performance. Compared to air quality, measuring ITS deployment is substantially more complicated. While air quality measures have the advantage of being relatively standardized in terms of monitoring and reporting for regulatory purposes, there is no accepted measure of the ITS intensity of a metropolitan area.

One approach to measuring levels of deployment of ITS in US cities would be to track the spending levels on ITS (for example, as a percentage of total transportation spending or per capita spending on ITS). However, breaking out the portion of total transportation spending on ITS has important barriers. First, funding of ITS projects usually requires a complex mix of federal, state and local money, and the categories for those funds vary widely in name and content from one area to another, making aggregation across funding categories difficult. Even looking only at federal aid funding, ITS can be funded through specific ITS earmarks, Congestion Management and Air Quality (CMAQ) program funds, Surface Transportation Program (STP) funds, and the larger highway and transit funding categories. Yet, ITS is usually only a small portion of each of those funding categories. Second, ITS is often incorporated as part of a larger traditional infrastructure projects, making it difficult to determine spending levels for the ITS components alone. For example, many agencies are now installing cameras, VMS and fiber optic cable at the same time that a highway is built or expanded. However, the costs of

113 Also see [www.epa.gov/oar/oaaqs/greenbk/anay.html](http://www.epa.gov/oar/oaaqs/greenbk/anay.html).
the ITS components are usually bundled in the total project costs. Accurately estimating ITS expenditures would require a project-by-project breakdown of the ITS content of each project. Finally, in contrast to traditional infrastructure projects, operational costs for ITS are a more significant fraction of overall project cost. These costs are also harder to track looking at transportation programs and plans.

The ITS Deployment Tracking database, maintained by the USDOT’s Joint Program Office,\textsuperscript{114} provides a large amount of data, collected and reported using a uniform format, on ITS deployments for 78 of the largest metropolitan areas in the US. Table 5-2 shows the categories of ITS indicators.

\textsuperscript{114} The database is available at http://itsdeployment2.ed.ornl.gov/its2002/. Last accessed November 15, 2005. Also see summary reports on each metropolitan area.
Table 5-2  ITS deployment indicators

<table>
<thead>
<tr>
<th>Electronic Fare Payment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixed route buses that accept electronic fare payment *</td>
</tr>
<tr>
<td>Rail transit stations that accept electronic payment</td>
</tr>
<tr>
<td>Arterial Management</td>
</tr>
<tr>
<td>Arterial miles covered by HAR</td>
</tr>
<tr>
<td>Arterial miles covered by VMS</td>
</tr>
<tr>
<td>Signalized intersections covered by electronic surveillance</td>
</tr>
<tr>
<td>Signalized intersections under centralized or closed loop control *</td>
</tr>
<tr>
<td>Emergency Management</td>
</tr>
<tr>
<td>Emergency management vehicles under CAD *</td>
</tr>
<tr>
<td>Emergency management vehicles with in-vehicle navigation capability</td>
</tr>
<tr>
<td>Incident Management</td>
</tr>
<tr>
<td>Arterial miles covered by CCTV</td>
</tr>
<tr>
<td>Arterial miles covered by free cellular phone call to a dedicated number</td>
</tr>
<tr>
<td>Arterial miles covered by incident detection algorithms</td>
</tr>
<tr>
<td>Arterial miles covered by service patrols *</td>
</tr>
<tr>
<td>Freeway miles covered by CCTV</td>
</tr>
<tr>
<td>Freeway miles covered by free cellular phone call to a dedicated number</td>
</tr>
<tr>
<td>Freeway miles covered by incident detection algorithms</td>
</tr>
<tr>
<td>Freeway miles covered by service patrols *</td>
</tr>
<tr>
<td>Electronic Toll Collection</td>
</tr>
<tr>
<td>Toll collection lanes with ETC *</td>
</tr>
<tr>
<td>Toll collection plazas with ETC</td>
</tr>
<tr>
<td>Freeway Management</td>
</tr>
<tr>
<td>Freeway miles covered by HAR</td>
</tr>
<tr>
<td>Freeway miles covered by VMS</td>
</tr>
<tr>
<td>Freeway miles under electronic surveillance *</td>
</tr>
<tr>
<td>Freeway miles managed by lane control</td>
</tr>
<tr>
<td>Ramps controlled by ramp meter</td>
</tr>
<tr>
<td>H-R Intersections</td>
</tr>
<tr>
<td>HRI under electronic surveillance *</td>
</tr>
<tr>
<td>Transit Management</td>
</tr>
<tr>
<td>Fixed route transfer locations with electronic display of information</td>
</tr>
<tr>
<td>Fixed route vehicles with AVL *</td>
</tr>
<tr>
<td>Fixed route vehicles with electronic monitoring of vehicle components</td>
</tr>
<tr>
<td>Paratransit vehicles under CAD</td>
</tr>
<tr>
<td>Regional Multimodal Traveler Information</td>
</tr>
<tr>
<td>Freeway management agencies disseminating information to the public *</td>
</tr>
<tr>
<td>Methods used</td>
</tr>
<tr>
<td>Methods used for more than two modes</td>
</tr>
</tbody>
</table>

Source: (Oak Ridge National Laboratory 2004)

The data is survey based, including all state, county and city agencies falling under the categories of freeway management, arterial management, fire rescue, law enforcement and transit
management. The number of surveys sent out to each metropolitan area therefore varies widely, from 12 agencies surveyed in Tulsa, Oklahoma, to nearly 60 agencies in Los Angeles, and as will be discussed, the response rate is high. Although the data is comprehensive, there are still several important issues in using the data from the ITS deployment database.

- **Which Technologies?** Given the number and diversity of ITS applications, the most basic issue is simply deciding which technologies or functions to include or not in a measure of ITS. This is compounded by the fact that new technologies are continuously emerging, with new technologies being developed and older technologies becoming obsolete. For consistency of comparison across years, the definitions of the technologies’ functions used here are held constant, for example, “freeway management agencies disseminating information to the public” rather than focusing on the technology used to disseminate that information, such as internet, email alerts, text messaging, telephone, or kiosks.

- **Effectiveness/Intensity of Usage.** Simply having a particular technology installed does not guarantee that the technology is used effectively or intensively. This can vary widely over time and between cities. To illustrate, variable message signs, which can provide real-time information and instructions to drivers can vary widely in terms of their intensity of use (how often are messages updated, how many organizations can input messages), and effectiveness of use (how relevant and accurate is that information, how effective are messages at rerouting traffic, or whether the messages are even related to traffic or are simply general public announcements). For this reason, the indicator can be considered only a rough scale of ITS deployment levels, instead of using it to make detailed comparisons between cities.

As an example of the difference between deployment levels and effectiveness (or perceived effectiveness), Chicago is looking toward Houston and Los Angeles as representing “best practices” in ITS and traffic management, although the indicators show Chicago with slightly higher levels of deployment than Houston, and substantially higher levels than Los Angeles. Furthermore, although Los Angeles is frequently cited as an example of advanced use of ITS technologies, its ranking according to the ITS summary indicator is, in fact, low. This can also be due to the size of the city, as will be discussed below.

- **Normalizing.** Finally, there is the issue of comparison of ITS deployment across different cities, and how to normalize ITS deployments for the size of the metropolitan area, and other factors such as modal split and demographics. One can either normalize ITS deployments using population or the amount of traditional transportation infrastructure, i.e. freeway miles, arterial miles, number of buses, number of stations, or number of toll collection plazas. While normalizing ITS to population would theoretically give a sense of the amount of ITS services available to individuals, in most cases, normalizing ITS deployments to infrastructure is a more appropriate measure, as it indicates the level of ITS deployment that is physically possible in terms of freeway or arterial miles covered or percentage of buses with ITS installed. Using the

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percentage of infrastructure covered could create a bias, with smaller cities showing relatively higher levels of ITS coverage, and larger cities with lower coverage. This would be due more to the relative amount of traditional physical infrastructure in place than to the amount of ITS deployed. Figure 5-2 indicates that the relationship may be an inverted U-shape, with ITS deployment coverage increasing with city population until a certain point, when the size of a metropolitan area makes extensive coverage of a city’s infrastructure increasingly difficult.

**Figure 5-2 ITS deployment and population**

- **Aggregation.** In order to develop a single metric for ITS deployment levels, we have used a summary indicator, based upon the ten primary indicators used by the ITS Deployment Tracking Database to summarize deployment levels. These ten indicators are identified by a star (*) in Table 5-2. This summary indicator represents the average percent deployment across these ten categories. This avoids to some extent the possibility of double counting, in particular, the double counting of “no responses” from the same agency. As seen in Figure 5-3, the summary indicator used here is a good proxy for a full indicator that would incorporate all 31 categories listed in Table 5-2.

- **Response Rate.** The ITS deployment database has the advantage of both a relatively high response rate, and several years of collecting the same data from the same organizations (for the
years 1997, 1999, 2000, and 2002). Only Orlando, Hampton Roads, Baltimore, Tulsa, San Juan fell below 75% response rate for all 29 categories for 2002. However, the use of the summary indicator (for 10 categories) mitigates possible problems with no responses, since the summary indicator does not include the categories most frequently reporting no-response. Furthermore, because multiple years are collected, a "no response" can be compared with earlier years. "No responses" were treated here as 0% deployment. Looking at several cities, and comparing to results from earlier years, that seems to be a reasonable assumption, meaning that agencies typically did not respond because they had nothing to report. Only 2002 deployment data is used in the analysis, since this represents the cumulative ITS deployment undertaken during the mid to late-1990s (assuming that most ITS deployments will be maintained, if not expanded).

**Figure 5-3 Comparison of summary ITS indicator and full ITS indicator (2002 survey)**

Using the summary indicators for ITS coverage, the 78 metropolitan areas in this analysis can be divided into three categories: (1) high ITS deployment with 40% or greater infrastructure coverage, (2) medium ITS deployment with 20%-39% infrastructure coverage, and (1) low ITS deployment with less than 20% infrastructure coverage. As can be seen in Table 5-3, the majority of the cities fall within the medium ITS deployment category.

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116 Data for the 2004 deployment survey became publicly available in the summer of 2005. However, the cases had already been chosen that the fieldwork underway when the data was released. Therefore, the data presented here is from the 2002 survey, unless otherwise noted.

117 The highest level is that of Washington, DC with 60% ITS coverage.
Table 5-3 Classification of metropolitan areas by level of ITS deployment

<table>
<thead>
<tr>
<th>HIGH (25 areas)</th>
<th>MEDIUM (39 areas)</th>
<th>LOW (13 areas)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(40% or greater)</td>
<td>(20%-39%)</td>
<td>(0%-19%)</td>
</tr>
<tr>
<td>Washington, DC</td>
<td>New Orleans, LA</td>
<td>Knoxville, TN</td>
</tr>
<tr>
<td>Detroit, MI</td>
<td>Denver, CO</td>
<td>Honolulu, HI</td>
</tr>
<tr>
<td>San Antonio, TX</td>
<td>San Diego, CA</td>
<td>Pittsburgh, PA</td>
</tr>
<tr>
<td>Cincinnati, OH</td>
<td>Kansas City, MO</td>
<td>Sarasota-Bradenton, FL</td>
</tr>
<tr>
<td>Portland, OR</td>
<td>Buffalo, NY</td>
<td>Youngstown, OH</td>
</tr>
<tr>
<td>San Francisco, CA</td>
<td>Albany, NY</td>
<td>Albuquerque, NM</td>
</tr>
<tr>
<td>Chicago, IL</td>
<td>Rochester, NY</td>
<td>Memphis, TN</td>
</tr>
<tr>
<td>Miami, FL</td>
<td>El Paso, TX</td>
<td>Scranton, PA</td>
</tr>
<tr>
<td>Salt Lake City, UT</td>
<td>Charleston, SC</td>
<td>Grand Rapids, MI</td>
</tr>
<tr>
<td>Minneapolis-St. Paul, MN</td>
<td>Omaha, NE</td>
<td>Providence, RI</td>
</tr>
<tr>
<td>Greensboro, NC</td>
<td>Charlotte, NC</td>
<td>Harrisburg, PA</td>
</tr>
<tr>
<td>Allentown, PA</td>
<td>Dayton, OH</td>
<td>Baton Rouge, LA</td>
</tr>
<tr>
<td>Atlanta, GA</td>
<td>Hampton Roads, VA</td>
<td>Tulsa, OK</td>
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<tr>
<td>Milwaukee, WI</td>
<td>Dallas-Fort Worth, TX</td>
<td></td>
</tr>
<tr>
<td>Sacramento, CA</td>
<td>Fresno, CA</td>
<td></td>
</tr>
<tr>
<td><strong>Orlando, FL</strong></td>
<td>West Palm Beach, FL</td>
<td></td>
</tr>
<tr>
<td><strong>Houston, TX</strong></td>
<td>Oklahoma City, OK</td>
<td></td>
</tr>
<tr>
<td>Columbus, OH</td>
<td><strong>Los Angeles, CA</strong></td>
<td></td>
</tr>
<tr>
<td>Seattle, WA</td>
<td>Las Vegas, NV</td>
<td></td>
</tr>
<tr>
<td>Philadelphia, PA</td>
<td>Hartford, CT</td>
<td></td>
</tr>
<tr>
<td>New York, NY</td>
<td><strong>Boston, MA</strong></td>
<td></td>
</tr>
<tr>
<td>Phoenix, AZ</td>
<td>New Haven, CT</td>
<td></td>
</tr>
<tr>
<td>Syracuse, NY</td>
<td>Tampa, FL</td>
<td></td>
</tr>
<tr>
<td>Tucson, AZ</td>
<td>Bakersfield, CA</td>
<td></td>
</tr>
<tr>
<td>Indianapolis, IN</td>
<td>Cleveland, OH</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Austin, TX</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Raleigh-Durham, NC</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Wichita, KS</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Little Rock, AR</td>
<td></td>
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<tr>
<td></td>
<td>St. Louis, MO</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Greenville, SC</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Toledo, OH</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Jacksonville, FL</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Richmond, VA</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Nashville, TN</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Birmingham, AL</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Springfield, MA</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Louisville, KY</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Baltimore, MD</td>
<td></td>
</tr>
</tbody>
</table>

The high levels of ITS deployment can be explained relatively easily for some cities, for example, finding San Antonio, Seattle, and Phoenix with relatively high levels of ITS can be explained by their participation in the federal MMDI program for integrated ITS deployment. Salt Lake City can be explained in part by its preparation for hosting the Winter Olympics,
Washington, as the home of the FHWA and FTA, and Detroit, as the home of General Motors, which helped sponsor many early pilot deployments of ITS. Houston, Chicago-Gary-Milwaukee, and Southern California were also chosen for federal funding as “Priority Corridors” for ITS deployment and integration. Success in obtaining Congressional earmarks for specific projects and initiatives have also been an important factor for deployment of ITS in several cities.

Congestion provides a motivation to look at all possible measures to improve travel time and reliability of travel time. With increasing severity of congestion, ITS is seen as a tool to reduce both recurrent and non-recurrent congestion. Therefore, in Figure 5-4, we show the relationship between congestion levels and ITS deployment.

Figure 5-4 Congestion and ITS

The explanatory power of congestion is not as strong as might be expected (with an R-squared value of 0.20). Congestion as an explanatory variable for why cities would have more or less ITS, is also incomplete without air quality and other environmental factors also coming into play. Many transportation agencies would prefer to continue their strategy of building additional infrastructure to address congestion. However, air quality and other environmental regulatory restrictions make that strategy increasingly harder to follow. Therefore, ITS is often used as a measure or “delaying tactic” to mitigate congestion until additional infrastructure can be built or even as a permanent solution to congestion in areas where environmental limits do not allow for additional or expanded physical infrastructure.
Now that we have reviewed the indicators used for both air quality and ITS deployment levels, we will now discuss how they are used to compare air quality and ITS for individual cities, and to select cases.

5.2.3 Comparing ITS Deployment and Air Quality

Figure 5-5 shows how the 78 US metropolitan areas are distributed according to their ITS deployment levels and air quality for 1-hour ozone according to the NAAQS. Using these measurements of ITS coverage and ozone non-attainment levels, we can classify metropolitan areas into different categories. In the upper right-hand quadrant of Figure 5-5, we find a grouping of cities with major air quality issues as well as high levels of ITS deployment, which includes many of the largest metropolitan areas such as New York, Chicago, Philadelphia, Houston, Atlanta and Washington, DC. We would also expect that these cities would have the greatest level of ITS due to restrictions on capacity expansion, and high levels of experimentation with the use of ITS technologies as a tool for emissions reductions and air quality improvements.

In the lower, left-hand quadrant, we observe the other end of the spectrum, cities with relatively minor air quality problems, and only a minimal deployment of ITS, cities such as Tulsa, Albuquerque, Harrisburg, Grand Rapids, and Knoxville. In doing case study analysis, comparisons must be done carefully, since cities within the former category (high air quality, high ITS) have a plethora of material documenting their actions and decisionmaking processes, given both their struggles with air quality and relatively impressive levels of ITS deployment, while cities within the former category (low air quality, low ITS) are only outstanding because of their minimal problems with air quality and rather lukewarm embrace of ITS applications. However, this category also deserves investigation, due to (1) the large number of cities that fall within this category, (2) the contrast that cities such as Tulsa, Memphis and Birmingham provide as counter cases to cities such as Houston and New York, and (3) the fact that several of the cities will likely begin to face more pressing air quality regulatory challenges with the enforcement of the stricter 8-hour ozone and PM 2.5 national ambient air quality standards. Although these cities have historically been in attainment with the 1-hour ozone standard, the 8-hour ozone is a more difficult air quality standard to meet. Tulsa is chosen as a within this category of low ITS, no air quality problems. Indeed, as will be discuss later, with the new 8-hour ozone standard, Tulsa has come close to the borderline of becoming a non-attainment area for the first time since the 1990 CAAA.

The other set of cities are those that have serious, severe or extreme air quality problems but have deployed relatively little ITS, and cities that, on the other hand, have an absence of major air quality concerns, but also have widely deployed ITS. One of the more interesting cases will be that of Los Angeles, which despite persistently having the worst air quality in the country, 

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118 While the 1-hour ozone standard was 0.12 ppm, measured in hourly readings, the 8-hour ozone standard is set lower at 0.08 parts per million (ppm), taking the average over eight hours. EPA (2004). Fact Sheet: Clean Air Ozone Rules of 2004, Final Rule Designating and Classifying Areas Not Meeting the National Air Quality Standard for 8-Hour Ozone. See www.epa.gov/ozone-designations/finrulefs.htm. Last accessed February 11, 2006. Webpage last updated December 19, 2005.
appears to have lower than average levels of ITS deployment in terms of infrastructure coverage compared to other cities. Although, as discussed earlier, the ITS deployment indicator may not be an entirely accurate measure of a city's level and, more specifically, effectiveness of ITS, with some biases against larger cities. Alternatively, there are a number of cities with major ITS deployments, across all categories of ITS applications, and no major air quality concerns. This includes cities such as Orlando, San Antonio, Salt Lake City, and Cincinnati. We will take the case of Orlando to ask if in the absence of air quality concerns, they will utilize their well-developed ITS infrastructure to pursue air quality benefits as well.
Figure 5-5  ITS deployment and air quality for 78 US metropolitan areas
5.2.3.1 Effect of Air Quality Regulation on ITS Deployment

Another interesting question is whether the effect of air quality regulations is significant enough to identify a contribution to the overall level of ITS implementation. The decision to deploy any single ITS technology is the result of number of factors, and as discussed in the previous chapter, the level of experimentation with ITS for air quality purposes is dependent on many organizational and institutional conditions. Poor air quality may provide a motivation to look beyond traditional capacity expansion, which is increasingly seen as inducing additional vehicle travel and thus greater emissions. ITS applications, in contrast, are often viewed by transportation agencies as a way to mitigate congestion in a way that is beneficial or neutral to air quality. For example, the case studies will show that many areas use ITS deployments as emission reduction measures in their air quality plans, and have funded many ITS applications through the Congestion Mitigation and Air Quality program federal funding category, which requires estimates of emissions reductions. Figure 5-4 shows that congestion, measured using the Travel Time Index (TTI)\textsuperscript{119} reported annually in the Texas Transportation Institute's Urban Mobility Report, better predicts levels of ITS deployment than air quality.

5.2.3.2 The Effect of ITS on Air Quality

There is also the question of the effect of ITS on air quality, bringing us back to Chapters 2 and 3, which examined the possibilities of ITS to lead to emissions reductions (or increases in some cases). However, by using the 1991 attainment/nonattainment designations and classification and levels of ITS deployment since that time, we avoid this potential feedback loop. Furthermore, if the 2002 CMAQ review by TRB is any guide (Transportation Research Board 2002), the answer will be that the impact on a metropolitan or regional level is small, and that ITS probably has not been enough in itself to move an area to a lower non-attainment category or into attainment status.

Instead of relying on a statistical analysis, the focus will be on carefully choosing a set of cases that represent different combinations of levels of ITS deployment and air quality status (a measure of problem severity, as described in Chapter 4).

\textsuperscript{119} The Travel Time Index measures the "ratio of travel time in the peak period to the travel time at free-flow conditions" Schrank, D. and T. Lomax (2005). The 2005 Urban Mobility Report. College Station, TX, Texas Transportation Institute. Therefore, taking the case of Los Angeles, a TTI of 1.75 means that a peak period trip would be 75% longer than if that trip were taken during free-flow conditions. For example, a 30 minute free-flow trip would take about 53 minutes during the peak period.
5.3 OVERVIEW OF CASE STUDIES

5.3.1 Selection of Case Studies

Cities were selected in order to represent a broad range of level of ITS coverage, from minimal deployment of 10% infrastructure coverage in Tulsa, Oklahoma to 45% in Orlando, Florida and Houston, TX,\(^{120}\) while also including cities from various ozone non-attainment classifications. Two areas in attainment are included, while three non-attainment areas, including serious, severe and extreme, are also included. Cities were also selected to show diversity in population, levels of congestion, geographic region, and rates of population growth (see Table 5-4 and Figure 5-6). While this allows for some diversity across levels of ITS deployment and air quality, it cannot be asserted that the selected cases are representative of their categories.

We chose what would be considered two extreme cases, in terms of air quality problems as well as existing levels of ITS deployment, and three other cities that were intended to (and did) capture a range of IIDAPT outcomes. The five cities chosen were Los Angeles (California), Houston (Texas), Boston (Massachusetts), Orlando (Florida), and Tulsa (Oklahoma). It should be noted, that because the levels of IIDAPT for each city could only be assessed after the fieldwork was completed and the cases were analyzed, cases could not have been chosen purposefully to reflect a range of IIDAPT outcomes. But, we found that the cases also presented a good distribution of IIDAPT outcomes from low to high.

\(^{120}\) Comparing the results of Houston’s deployment for earlier years, it appears that there may have been some underreporting in 2002, in particular, in the number of signalized intersections under centralized or closed-loop control.
Table 5-4 Comparison of cities selected for case studies

<table>
<thead>
<tr>
<th>Ozone Problem</th>
<th>Boston, MA</th>
<th>Houston, TX</th>
<th>Los Angeles, CA</th>
<th>Orlando, FL</th>
<th>Tulsa, OK</th>
</tr>
</thead>
<tbody>
<tr>
<td>1991 Designation</td>
<td>Serious</td>
<td>Severe-17</td>
<td>Extreme</td>
<td>Attainment</td>
<td>Attainment</td>
</tr>
<tr>
<td>ITS Deployment</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Level</td>
<td>Medium</td>
<td>High</td>
<td>Medium</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Rank (of 76)</td>
<td>45</td>
<td>15</td>
<td>43</td>
<td>15</td>
<td>76</td>
</tr>
<tr>
<td>Summary Indicator</td>
<td>30%</td>
<td>45%</td>
<td>31%</td>
<td>45%</td>
<td>10%</td>
</tr>
<tr>
<td>Population</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1990</td>
<td>4,133,895</td>
<td>3,767,335</td>
<td>11,273,720</td>
<td>1,224,852</td>
<td>761,019</td>
</tr>
<tr>
<td>2000</td>
<td>4,391,344</td>
<td>4,715,407</td>
<td>12,365,627</td>
<td>1,644,561</td>
<td>859,532</td>
</tr>
<tr>
<td>Rank (all MSAs)</td>
<td>10</td>
<td>8</td>
<td>2</td>
<td>30</td>
<td>53</td>
</tr>
<tr>
<td>Ave. annual growth</td>
<td>0.6%</td>
<td>2.3%</td>
<td>0.9%</td>
<td>3.0%</td>
<td>1.2%</td>
</tr>
<tr>
<td>Congestion Levels</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Travel Time Index</td>
<td>1.34</td>
<td>1.42</td>
<td>1.75</td>
<td>1.30</td>
<td>1.10</td>
</tr>
<tr>
<td>Rank (of 85)</td>
<td>21</td>
<td>6</td>
<td>1</td>
<td>26</td>
<td>64</td>
</tr>
</tbody>
</table>

Sources: Population121 from 1990 and 2000 Census (U.S. Census Bureau 2003); Ozone Designations (U.S. Environmental Protection Agency 2004); ITS Deployment, author’s calculations from (Oak Ridge National Laboratory 2004); Congestion ranking and travel time index from 2003 data (Schrank and Lomax 2005).

Figure 5-6 Geographic distribution of case studies

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121 Population figures reflect the metropolitan statistical areas (MSAs) defined by the Office of Management and Budget as of June 6, 2003: Boston-Cambridge-Quincy, Houston-Baytown-Sugar Land, Los Angeles-Long Beach-Santa Ana, Orlando, and Tulsa. This figures may differ from the numbers used by the metropolitan planning...
5.3.2 Methodology

Although the methods used for the cases have been discussed implicitly, we will briefly discuss the methods used here in the more formal language of research design. The methods used in this chapter represent a hybrid between a case study, which provides a highly detailed, intensive account of a single case or closely related cases, and a survey, which involves the uniform collection of information and data from a sample of people or organizations. Our approach resembles a case study in the format by which the information will be presented for each city, as well as the variety of data collection techniques employed, including analysis of documents, interviews, and observation. However, whereas case studies typically focus on a single case or small number of very similar cases, documented with highly specific detail and long-term observation, we will explore five distinct cases with somewhat less detail for each case. Therefore, in addition to detailed case description, we also look at a larger number of cases that serve as appropriate comparisons or “counter-cases” to our thesis. This addresses the criticism that arises when cases are chosen to reflect only desired outcomes (Robson 1993, p 61). In this sense, the research lies more in the direction of a survey approach. Because of the relatively small number of cases explored – five out of the population of 78 US metropolitan areas – we have used what is called purposive sampling. Rather than random sampling, we have chosen our five cases based upon various degrees of ITS deployment and air quality problems. This both allows for deliberate and detailed comparison of cases, and increases the scope of data examined (Robson 1993, p 61).

While a standard survey approach would utilize a uniform format for the interviews, we instead used a more flexible “semi-structured” (i.e. open-ended questions) interview format, recognizing the more exploratory nature of establishing the air quality-ITS relationships, gathering information that could be used to describe our seven conditions, and identify other possible conditions contributed to IIDAPT outcomes. The semi-structured interview was also more appropriate given the diversity of organizations and individuals interviewed for each case. A variety of additional data sources were used to supplement the information gathered in the interviews, including primary sources such as long-range transportation plans, state air quality implementation plans, transportation improvement plans, committee meeting minutes and public comments, etc., and secondary sources such as published and non-published articles and reports, external planning reviews, project evaluations, and newspaper articles.

5.3.3 Objectives of Interviews

The interviewees selected for each case include transportation planners, engineers and managers of ITS and other operations programs, air quality program managers, participants in metropolitan planning organizations (MPOs), and consultants. In nearly all cases, interviewees from state DOTs, city and county transportation agencies, state air quality/environmental agencies, transit agencies, and MPOs were included as the principal interviewees.
General issues addressed in the interviews included, but were not limited to the following (see Appendix D for the full interview protocol):

- Has the city experimented with ITS as a tool to reduce emissions and improve air quality?
- Which ITS applications are deployment at least partially justified or promoted by their potential air quality impacts?
- Have evaluations of emissions impacts of ITS been undertaken, and what effect do those evaluations have on future deployments or modifications to the system?
- Has the city turned more toward ITS investments as a result of stricter air quality regulation?
- If yes, was this due to restrictions on traditional capacity expansion, requirements for implementing TCMs, or money provided through the CMAQ program?

Because we are looking at the metropolitan level, we need to look at all IIDAPT for ITS and air quality. Our research methodology attempted to cover all possible IIDAPT. First, was through the interview process. Asking participants to identify technologies with an air quality benefit. The second, was to review air quality and transportation plans and programs for inclusion of ITS in CMAQ or inclusion of ITS as a TCM, or otherwise included in a transportation plan or program or air quality plan. There was cross checking of information obtained from the interview process, the review of official documents, and secondary analysis. This allowed us not only to cast the net more broadly to identify possible examples of IIDAPT, but also to measure IIDAPT levels for each individual technology, and even exclude some candidate IIDAPTs.

Having discussed the aggregate data for ITS and air quality, case selection, and methodology, we now turn to our five cases.
5.4 HOUSTON, TEXAS

5.4.1 Background

5.4.1.1 The City

With over 4.7 million residents and an area of over 7,000 square miles, Houston is often characterized by its critics as a sprawling, auto-oriented city, that reflects the “Texas obsession with highway construction.” Or, as described more euphemistically in the 2025 Regional Transportation Plan (RTP):

“The decentralized development pattern that has emerged in Houston since the 1960s has contributed to an enlarged urbanized area that is now characterized by multiple major employment centers, employment corridors, and other activity districts outside of the CBD” (Houston-Galveston Area Council 2005, p 36).

According to transportation specialists in the Houston area, economic vitality and growth predominate in the decisionmaking process, a view also reflected in the opening lines of the RTP, that “the Houston-Galveston region will continue to be a dynamic economic center in 2025” (Houston-Galveston Area Council 2005, p 1). Indeed, Houston is noteworthy in the extent to which economic forces seem to predominate in the decisionmaking processes for planning. In the arena of land-use planning, for example, Cervero refers to Houston as “a city that even shuns zoning” (Cervero 2002, p 434). Yet, as noted both by Cervero as well as Garreau, in his analysis of “Edge Cities” in the US, the hand-offs approach to zoning has also generated subcenters of high-density and mixed-use development in areas such as the high-end Galleria area (Garreau 1991; Cervero 2002). Growth in sprawl and traffic has also had an impact on air quality. The eight-county Houston-Galveston region is designated as Severe-17 non-attainment for ozone, following Los Angeles as the worst air quality in the nation.

5.4.1.2 Transportation

Population and travel in the region have grown substantially, with population growing at an average of over 2% during the 1980s and 1990s, and VMT outpacing population and even employment growth (Houston-Galveston Area Council 2005, p 21). Houston continues to suffer some of the worst congestion in the nation, ranking sixth according to the 2005 Travel Time Index (Schrank and Lomax 2005). Vehicle miles traveled (VMT) are expected to continue to increase from about 125 million daily VMT in 2000 to over 200 million in 2035 (Houston-Galveston Area Council 2005, p 21). To accommodate this demand and address the “roadway

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124 This projection suggests that population and VMT will grow at approximately the same rate of 2% annual growth, however, this seems to be a conservative estimate compared to recent trends in VMT versus population growth.
system deficiency,” the MPO and the partner agencies have developed an ambitious plan of continued highway expansion – through a mix of freeways, tollways and managed lanes, as well as increased investment in transit, including extensions of the recently opened light rail (METRORail) service, new bus routes and transit centers, and the implementation of commuter rail lines.

**Figure 5-7 Map of Houston Metropolitan Area**

![Map of Houston Metropolitan Area](source: www.mapquest.com)

While there continues to be a strong tendency toward the use of the auto as a single occupancy vehicle, Houston has also developed an extensive network of HOV lanes for carpools, vanpools and buses. Currently, over 100 miles of HOV lanes are available on six freeway corridors, with supported elements including 28 park-and-ride lots, 4 park-and-pool lots, transit centers, express buses, and direct access ramps (Turnbull 2003). From the beginning, the HOV lanes in Houston were oriented more toward express bus service and vanpools than carpools of two or three occupants. Indeed, when the first HOV counterflow lanes opened beginning in 1979 on I-45, only buses and vanpools were permitted to enter the lane. Not until 1985 were authorized
carpools of four persons allowed to use the lanes\textsuperscript{125} (Turnbull 2003, p 11). Increasingly, funding priority has been given to transit expansions, including a recently opened light rail line, METRORail, which connects some of the major employment centers in Houston. Indeed, according to Cervero, Houston was one of the only metropolitan areas in the US to see recent increases in both absolute transit ridership and the percentage share of transit in the overall modal split (Cervero 2002).

High congestion levels and limits on cost-feasible expansion options have also brought increasing attention on the need to increase mobility options, reduce the growth rate in VMT, and improve the transportation system’s operation. The RTP identified three key policy areas: “(1) increase highway and transit system capacity (where feasible and affordable), (2) improve operations management of existing facilities, (3) manage the demand for peak-period travel” (Houston-Galveston Area Council 2005, p ii). Therefore, while there is still a focus on system expansion, much more so than older cities such as Boston, this suggests a more balanced approach to transportation investment that has important consequences not only for congestion, but also for air quality and ITS deployment. However, it also shows that while transportation planners consider it necessary to manage demand for peak-period travel, there has not been a shift toward reducing total demand.

5.4.1.3 Institutions

The Houston-Galveston metropolitan area includes Harris County, where the City of Houston is located, as well as seven additional surrounding counties.\textsuperscript{126} The majority of ITS efforts are headed by four agencies – City of Houston, Harris County, Texas Department of Transportation (TxDOT), and Harris County Metropolitan Transit Authority (METRO) – which are the agencies which came together to form the Houston TranStar Traffic Management Center.

The Houston Metropolitan Area has some unique organizational structures in that its transit agency, Metropolitan Transit Authority of Harris County (METRO) also takes part in traffic management and roadway capital projects, and has its own transit police force for not only the transit system, but also for the HOV lanes and freeways. This unusual organizational role was, in part, the result of the HOV projects first undertaken in 1979, the same year that METRO was created. More recently, METRO has also taken on traffic signalization projects, incorporating transit signal priority at hundreds of intersections. A one-cent sales tax has made METRO a well-funded transit agency – with a total revenue of 564 million in FY 2004, 384 million of which come from the sales tax – allowing METRO to branch out in terms of its activities (Metropolitan Transit Authority of Harris County (METRO) 2004, p F-20).

\textsuperscript{125} The carpool occupancy limit was eventually lowered to three and two occupants, although a degradation of service levels from an excess of two-person carpools eventually forced the minimum back up to three occupants on some HOV lanes at peak hours. Turnbull, K. F. (2003). Houston Managed Lanes Case Study: The Evolution of the Houston HOV System. College Station, TX, Performed by Texas Transportation Institute for the Federal Highway Administration, Operations Office of Transportation Management: 48 pages.

\textsuperscript{126} The eight counties in the Houston region include Harris, Galveston, Chambers, Liberty, Montgomery, Waller, Fort Bend, and Brazoria.
The Houston-Galveston Area Council (H-GAC) serves as the region’s Metropolitan Planning Organization (MPO), and therefore has primary responsibility for regional transportation planning and air quality conformity analysis in the eight-county area which is in non-attainment for ozone. H-GAC acts as the staff, to the Transportation Policy Council, which makes the final decisions on allocating transportation funds and project priorities. In addition to its role in transportation and air quality planning, H-GAC in recent years has largely taken on the responsibility of ensuring the regional consistency of ITS deployment, both supporting the development of an ITS Architecture and standards for the region, as well as incorporating ITS into the mainstream transportation planning and funding process.

In terms of air quality management, H-GAC must also work with the Texas Commission on Environmental Quality (TCEQ) for development of the Houston-Galveston sections of the State Implementation Plan (SIP) for complying with the Clean Air Act. This includes identification of measures such as Transportation Control Measures to reduce on-road mobile source emissions necessary in order to stay within the mobile emissions budget.

### 5.4.2 Air Quality History

After Los Angeles, designated as extreme non-attainment, Houston is the metropolitan area with the highest ozone levels in the county. During the 1990s, it was common for at least one of the 27 monitors in the region to exceed the standards between 40-50 days of the year (see Figure 5-8). In part, this is due to a long “ozone season” in Houston, where ozone exceedances can and do occur anytime from March to November.

![Figure 5-8 Number of days when a monitor exceeded the 1-hr ozone standard](image)

*Source: (Houston-Galveston Area Council 2002, p 19)*

127 TCEQ was formerly the Texas Natural Resource Conservation Commission. The name was changed in 1991.
5.4.2.1 Sources

For NOx and VOC, on-road mobile sources (e.g. cars, trucks, motorcycles, buses and other vehicles on the roadway) are an important source. However, they are not the predominate source for either of the ozone precursors in Houston. For example, biogenic sources (e.g. crops, trees, etc.) represent the majority of VOC emissions, while non-road mobile emissions (e.g. construction equipment, lawn mowers, recreational boats, aircraft operations) predominate for NOx. Excluding biogenic sources, which do not enter into control strategies, on-road mobile emissions contribute to 20% of VOC, and 28% of NOx. Point sources (e.g. refineries, manufacturing facilities, power plants) outweigh on-road mobile sources for both NOx and VOC. For CO, on and off-road mobile source emissions provide the vast majority of emissions. However, Houston is in attainment for CO.128

Figure 5-9 Emissions inventory for the Houston-Galveston Area (2002)

No single source dominates for either VOC or NOx emissions, which are a mix of area, point and on-road and non-road mobile sources. In addition, unique meteorological conditions and chemistry lead to complex ozone formation in Houston. As a consequence, the strategies for reducing ozone have undergone constant reworking as new measurements and modeling improvements shed additional light on ozone formation, which has also had an impact on the conformity determination process in Houston.

Having been designated by EPA as “severe” non-attainment under the CAAA of 1990, Houston has until November 15, 2007 to meet the national ambient air quality standard for one-hour ozone. In order to document progress toward meeting those standards, the CAAA of 1990 also

required all areas classified as serious and above, to submit a revision of the State Implementation Plan (SIP) to EPA by November 1994, in which they would describe measures to achieve both VOC and NOx emissions, and provide a demonstration of attainment, using an Urban Airshed Model (UAM) (Texas Natural Resource Conservation Commission 2000, p.129). However, early UAM results highlighted major uncertainties regarding the relationship of VOC to NOx in ozone formation in the Houston region, and the modeling of future scenarios indicated that reducing NOx emissions could actually increase ozone levels (Texas Natural Resource Conservation Commission 2000, p. I-4). In light of this uncertainty, EPA granted a temporary NOx waiver valid until 1997, meaning that the area would be exempt from all NOx requirements, including the transportation conformity requirements. Houston’s first conformity analysis was therefore completed in 1997, using a 20-year planning horizon and a 1999 VOC budget as the base. Although the model results first showed that the area would exceed the VOC budget, by making changes to how vehicle-miles traveled were modeled for both highways and local streets, the area was able to keep within the budget and demonstrate conformity (Howitt and Moore 1999, p.116).

5.4.2.2 Actions

According to H-GAC and TxDOT, new federal standards for vehicle emissions and fuel efficiency have been the most effective measures in reducing mobile source emissions in Houston. Local control strategies, such as operational improvements, although considered important for conformity purposes, are seen as “an order of magnitude less consequential” in reducing actual levels of emissions (H-GAC interview, 2005). Nonetheless, Houston has adopted a wide range of local measures for point, area and mobile sources. For on-road mobile source emissions, local control strategies to reduce NOx and VOC are categorized under TCMs, the Voluntary Mobile Emission Reduction Program (VMEP), Transportation Emissions Reductions Measures (TERM), and the Texas Emissions Reduction Plan (TERP) (see Table 5-5).

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129 State Implementation Plans (SIPs) – which outline control strategies intended to meet national ambient air quality standard – were first required as part of the Federal Clean Air Act Amendments of 1977. SIP cover all non-attainment areas in the states and all pollutants. SIP “revisions” are submitted frequently, sometimes to make minor amendments and incorporate new information and modeling results, and at other times to rewrite entire control strategies.
### Table 5-5 SIP categories and examples of control measures in Houston

<table>
<thead>
<tr>
<th>TCM</th>
<th>VMEP</th>
<th>TERM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regional Computerized Traffic Signal System</td>
<td>Regional Computerized Traffic Signal System</td>
<td>Traffic Signal Timing Optimization</td>
</tr>
<tr>
<td>Transportation Demand Management (vanpooling, commute alternatives, high capacity transitway project)</td>
<td>“Commute Solutions” program (vanpooling, commute alternatives, additional transit service, etc.)</td>
<td></td>
</tr>
<tr>
<td>ITS (surveillance, freeway traffic management)</td>
<td>Clean Cities/Vehicle Program (truck and bus replacement or retrofit)</td>
<td></td>
</tr>
<tr>
<td>Transportation System Management (turn lanes, grade separations)</td>
<td>Smoking vehicle identification</td>
<td></td>
</tr>
<tr>
<td>Bike and Pedestrian Facilities</td>
<td>Vehicle scrappage program</td>
<td></td>
</tr>
<tr>
<td>Park and Ride Lots</td>
<td>Other</td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Source: (Houston-Galveston Area Council 2005, TCM, Appendix 9.14; VMEP, Appendix 9.5; TERM, Appendix 9.18)*

It is not necessary to delve into details on all of these categories; however, it is important to note that these categories do not always reflect the type of physical projects undertaken, for example, traffic signal coordination, bicycle or pedestrian facilities, or vanpooling. Instead, they often reflect the type of legal commitment made to those projects, as while be explained further on. For example, traffic signalization projects are found across three categories, while vanpooling, telecommuting and transit are found both under the TCM and VMEP categories. After 2000, many transportation demand management (TDM) measures were also changed from TCMs to VMEPs, making them voluntary measures.

For Houston, TCMs included in the SIP tend to emphasize traffic flow improvements (often through ITS-based strategies), bicycle and pedestrian projects, and some transit projects. TCMs have been an increasingly important component of meeting SIP requirements and emission reduction targets. When the SIP was revised in 1997, additional Transportation Control Measures (TCMs) were needed as VMT offsets, due to changes that had been made to both the Employee Trip Reduction (ETR) Program and the I/M program. Specifically, in 1995, the US Congress amended the controversial ETR provision in the Clean Air Act, allowing employer trip reduction programs to be implemented at the state’s discretion. Under this amendment, large employers would no longer be required to implement trip reduction programs that would increase vehicle occupancy and thus reduce VMT. This program therefore became a voluntary initiative managed through H-GAC. In terms of the I/M program, the test-on-resale component, requiring an additional inspection prior to title transfer of the vehicle, was discontinued. In order to meet the offset requirement to make up for the “loss reductions,” a number of additional TCMs were worked into the SIP, “high occupancy vehicle lanes, park and ride lots, arterial

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130 This includes projects completed after 2000, and projects pending (i.e., not let to contract but expected to be completed by the 2007 ozone attainment deadline.
traffic management systems, computer transportation management systems, and signalization” (Texas Natural Resource Conservation Commission 2000, p I-8).

However, TCMs require substantial management overhead in reporting on their progress, and require strict adherence to their schedules and commitments. So-called “slippage” can lead to disapproval of an air quality conformity determination, and may require extensive documentation explaining what caused the slippage. In the extreme case, failures to implement specific TCMs included in the SIP can delay the flow of federal transportation funds to the region. One strategy, which has also been adopted by other states, is to build in a formal TCM substitution process. In this manner, TCMs that will not be implemented on schedule—due to funding problems, withdrawal of sponsor’s support, public opposition—or will be less effective in reducing emissions that previously expected, can be substituted for other TCMs. Each state has taken a slightly different approach to building in a TCM substitution process. The May 2000 SIP revision for the state of Texas, for example, incorporated a provision that TCMs can be substituted by the MPO without revising the SIP, if the new measures provide equal to or greater emissions reductions (Eisinger and Niemeier 2004).

Another strategy to avoid conformity problems related to TCM slippage, is the use of the what is referred to as the “Transportation Emissions Reductions Measures” (TERMs) category. The creation of this category allows agencies to take credit for emissions reductions from certain transportation measures, without the legal requirements associated with incorporating these measures as official TCMs in the air quality plan (or SIP). Taking into account these administrative issues with TCMs, but wanting to claim some emissions credit for certain projects whose implementation schedule would be more uncertain, the TERM category was used to avoid inclusion in the SIP. Currently, TERMs include only intersection signalization projects. In 2004, 1,540 traffic signals were retimed and coordinated by the staff of the City of Houston and through its consultants. As noted by H-GAC, as a TCM they would have to “report on the progress of each individual intersection,” a daunting task if hundreds of intersections are to be included (H-GAC interview, 2005). This provided a way to incorporate “TCM-like projects” and take emissions credit for intersection timing improvements only as they are completed.

5.4.2.3 Issues

In terms of local control strategies, there has been a shifting balance between the use of strategies aimed at changing behavior and technology-based strategies. In part, this dynamic represents an adaptation to new information and photochemical modeling regarding the processes and sources involved in ozone formation in Houston, and, perhaps more significantly, reflects the interests and preferences of government agencies and regulated entities and individuals. Several local business leaders, specifically, the Business Coalition for Clean Air Appeal Group and additional industrial companies, balked at the magnitude of reductions (90% of NOx) that would be required of industrial sources in accordance with the 2000 SIP for the Houston region. Litigation by this group led to a Consent Order in 2001, which required an independent analysis of rapid ozone formation events and additional possible mitigation measures. An intensive measurement campaign, the Texas Air Quality Study (TexAQS) followed, involving more than 200 researchers and 40 organizations collecting NOx and VOC data using aircraft-based
measurements during ozone episodes in August and September of 2000 (Texas Commission on Environmental Quality 2004). That data was then incorporated in photochemical grid modeling of those episodes, showing that VOC emissions were underestimated, and that highly reactive VOCs (HRVOCs) played a vital role in rapid ozone formation. The focus of control strategies in the following SIP revisions in 2002, thus moved away from depending almost entirely on deep reductions in NOx, establishing a slightly more modest target of 80% reductions of point source NOx emissions, and phased-in reductions of HRVOCs.\textsuperscript{131} (Texas Commission on Environmental Quality 2004).

The back and forth between technology and behavioral strategies also reflects organizational attitudes. According to TCEQ, “historically, the commission has expressed a preference to implement technology-based strategies over behavior-altering strategies” (Texas Commission on Environmental Quality 2004, p 17). Although more rigorous behavior-based strategies have indeed been implemented or proposed, when the science has presented new findings or public pressure intense, these strategies have been discontinued or relaxed, ratcheting down the level of regulation of individual behavior. At the same time as the shift away from a NOx-reduction based strategy, a number of strong behavioral measures that had been adopted were removed from the SIP in the 2004 revision. In terms of mobile sources, the heavy-duty vehicle idling restriction was removed and three counties – Chambers, Liberty, and Waller – were removed from the vehicle inspection and maintenance program requirement (Texas Commission on Environmental Quality 2005). Also, the “strikingly unpopular” idea proposed by TCEQ to introduce an environmental speed limit strategy, lowering the speed limit to 55 mph to reduce emissions, principally NOx emissions that increase at higher speeds, was first suspended then removed entirely from the SIP.\textsuperscript{132} Indeed, in 2003 the 78\textsuperscript{th} Texas Legislature stepped in and actually “removed the TCEQ’s authority to determine speed limits for environmental purposes” (Texas Commission on Environmental Quality 2004, p 17). An earlier example of the preference toward technology-based strategies is evident in the 1997 SIP revision, which incorporated many technology-based TCMs – signalization, traffic and transportation management – in order to make up for the loss of the ETR and I/M programs, both of which were behavioral change policies that placed the ultimate burden of action (changing travel patterns or bringing vehicles in for inspection) on individual drivers.\textsuperscript{133}

There are doubts, however, whether this technology-oriented strategy will be sufficient to bring the Houston region into attainment with the national air quality standards. Looking at the trends in ozone reductions in Figure 5-8, it is clear that continuing with the same rate of improvement

\begin{footnotesize}
\begin{enumerate}
\item Specifica\,ly, there are four HRVOCs to be addressed in the first round of HRVOC reductions: ethylene, propylene, 1,3-butadiene, and butanes. Texas Commission on Environmental Quality (2004). History of the Texas State Implementation Plan (SIP). Austin, TX.
\item Bill Dawson, “Cleaner air could be painful for public; Businesses, drivers won’t breathe easy as deadline looms for area smog plan,” \emph{The Houston Chronicle}, December 20, 1999, p A-1.
\item Although it was the business groups that resisted mandatory trip reduction programs in Houston, it would ultimately be the motorists themselves who would have to change their behavior. Because I/M programs do not “restrict everyday behavior,” they are generally not as strongly resisted by elected officials. Howitt, A. M. and A. Altshuler (1999). The Politics of Controlling Auto Air Pollution. Essays in Transportation Economics and Policy. J. A. Gómez-Ibáñez, W. B. Tye and C. Winston. Washington, DC, Brookings Institution Press: 223-256.
\end{enumerate}
\end{footnotesize}
will not yield the emission reductions necessary to meet the national standard for ozone in the next several years. Indeed, comments on the SIP by the Sierra Club’s Houston office have suggested, “already there is a whispering campaign that is defeatist in its assessment of the ability of this SIP to reduce emissions enough.”[^134] Indeed, in many respects, this echoes the earlier experience in the Los Angeles region, when “the unstated position of [the South Coast Air Quality Management District] between 1977 and 1986 was ‘we will try to improve the air quality, but Los Angeles is never going to have clean air’” (Mazmanian 1999, pp 86-87). Yet, the experience to date in Houston would suggest that moving towards more stringent behavioral measures, would be difficult to implement.

In terms of highway expansion, although the air quality conformity process has not completely derailed any major infrastructure projects, it has led to major delays and substantive modifications to some projects. When asked about any major infrastructure projects that have been challenged on the basis of air quality issues, interviewees from both TxDOT and H-GAC responded “which one hasn’t?” (TxDOT and H-GAC interview, 2005). In this respect, one of the more contentious projects has been the Grand Parkway, the proposed third beltway loop around the fringes of the Houston metropolitan area, following the existing State Highway 99 (see Figure 5-10, where Interstate 610 and Beltway 8 form the first and second “loops”). Environmental groups such as the Houston Sierra Club and Houston Audubon Society threatened to file suit in 1993, based on both air quality and waterfowl habitat concerns, citing the urban sprawl that the outer loop highway could generate.[^135] The following year, there were conformity problems meeting the VOC budget and fiscal constraint requirement, leading to a scaling back in lanes and capacity (Howitt and Moore 1999, p 77). Currently, while the Grand Parkway is included as part of the Regional Transportation Plan of the future transportation network, its full completion, as envisioned in Figure 5-10, is far from guaranteed.

[^134]: Letter from Brandt Mannchen (Chair, Air Quality Committee, Houston Regional Group of the Sierra Club) to Shelley Whitworth, Houston-Galveston Area Council, March 22, 2006. Letter can be accessed at [www.h-gac.com/HGAC/Departments/Transportation/Air+Quality/default.htm](http://www.h-gac.com/HGAC/Departments/Transportation/Air+Quality/default.htm).

Although it seems that challenges based on environmental concerns affect a wide range of projects, most interviewees in Houston cited financial issues, in particular, the increasing costs of acquiring right-of-way as the primary barrier to capacity expansion (TranStar, TxDOT, and H-GAC interviews, 2005). Air quality and other environmental concerns, such as habitat destruction, although mentioned, were usually second on the list. However, as noted by H-GAC, with the conformity determination process, “federal law has built in a number of easy to grab hold of handles for those wishing to challenge project” (H-GAC interview, 2005).

5.4.3 ITS Deployment

In order to understand the trends and patterns of ITS in Houston, it is necessary to look at the history of TranStar, the innovative operations and management “architecture” which has formed the cornerstone of ITS deployment. The inter-organizational framework, created through the “Interlocal Agreement for a Regional Transportation Management Program” in 1993, has promoted high levels of deployment and integration of ITS between TxDOT, METRO, Harris County, and the City of Houston. In the same year, Houston received an important federal earmark, when it was designated as one of four ITS Priority Corridors in the US. Along with state and local funding matches, the Houston Priority Corridor Program would be funded by $22 million through fiscal year 1997. The Houston region has levels of ITS deployment substantially higher than the national average for the ITS indicators such as real-time traffic data collection for freeways, ETC capability, emergency management under Computer-Aided Dispatch, and freeway traffic information to the public (Gordon and Trombly 2003). The diversity of
Houston’s ITS applications can be seen in Table 5-6, which shows the legacy systems installed at the time of the writing of the 2003 ITS Strategic Plan (PB Farradyne 2002).136

<table>
<thead>
<tr>
<th>Application</th>
<th>System</th>
<th>Subsystem</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transportation/Traffic</td>
<td>TranStar</td>
<td>CCTV</td>
</tr>
<tr>
<td>Management Center</td>
<td></td>
<td>Loop Detectors</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Automatic Vehicle Identification (AVI)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Flood and Weather Warning Systems</td>
</tr>
<tr>
<td>Detection and Surveillance</td>
<td>High Occupancy Vehicle (HOV) Lanes</td>
<td>Ramp Metering</td>
</tr>
<tr>
<td>Technologies</td>
<td></td>
<td>Dynamic Message Signs (DMS)</td>
</tr>
<tr>
<td></td>
<td>Control Strategies</td>
<td>Signal Network</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Changeable Lane Assistance Signs (CLAS)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lane Control Signals</td>
</tr>
<tr>
<td>Traveler Information</td>
<td></td>
<td>Motorist Assistance Patrol (MAP) Program</td>
</tr>
<tr>
<td></td>
<td>Pre-trip and En-route Planning</td>
<td>Heavy Duty Wreckers</td>
</tr>
<tr>
<td></td>
<td>TranStar Web Page</td>
<td>Emergency Vehicle Preemption</td>
</tr>
<tr>
<td></td>
<td>Texas Travel Information System</td>
<td></td>
</tr>
<tr>
<td></td>
<td>METRO Line</td>
<td></td>
</tr>
<tr>
<td>Electronic Payment</td>
<td>Electronic Toll Collection</td>
<td>EZ Pass Toll Program</td>
</tr>
<tr>
<td></td>
<td>QuickRide Program</td>
<td>High Occupancy Toll (HOT) Lane</td>
</tr>
<tr>
<td></td>
<td>City of Houston</td>
<td>Airport Parking</td>
</tr>
<tr>
<td>Transit Management</td>
<td>Advanced Radio Communication System</td>
<td>Onboard System</td>
</tr>
<tr>
<td></td>
<td>Communication Center Subsystem</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Communication Subsystem</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Computerized Telephone Information System</td>
<td>Interactive Voice Response System</td>
</tr>
<tr>
<td></td>
<td>Integrated Vehicle Operation Management System (IVOMS)*</td>
<td>Personalized Bus Itinerary Service</td>
</tr>
<tr>
<td></td>
<td>METROLift</td>
<td>Variety of Advanced Transit Applications</td>
</tr>
<tr>
<td></td>
<td>Personal Public Transit Service offered to persons with disabilities</td>
<td></td>
</tr>
</tbody>
</table>

*Planned system in 2003
Source: (PBS&J and Battelle 2003, p ES-3)

While we will not go into detail for all of the ITS application areas, we will highlight some of the more important systems below.

5.4.3.1 Traffic

The Greater Houston Traffic and Emergency Management Center, more commonly referred to as TranStar, is a self-described “flexible and dynamic partnership” for ITS. Indeed, the Executive Director of TranStar is more of a facilitator or “referee” between the agencies than a Director per

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136 This list focuses primarily on user services for passenger transportation, and does not include emergency management, commercial vehicle operations, data warehouse, and communications.
se (TranStar interview, 2005). In terms of applications, the four major efforts of TranStar are the Transportation Management Center (located on Old Katy Road), traveler information, incident management, and flow signals (ramp metering). Although TranStar has been in existence since 1993, with operations in its current building beginning in 1996, the supporting technologies have been under development on freeways since the late 1980s. The current system now covers 240 miles of freeway, including:

- 353 closed circuit television (CCTV) cameras,
- 157 dynamic message signs (DMS),
- 12 highway advisory radio (HAR) installations,
- 108 flow signals at ramps,
- 239 Automatic Vehicle Identification (AVI) checkpoints,
- 41 roadway weather systems,
- 242 miles of fiber/communications systems,
- the Motorists Assistance Program (MAP),
- and central facility computer systems (Texas Transportation Institute 2005, p 5).

However, in addition to the physical system installations, probably the more important aspect of TranStar is its coordinating and capacity-building role.

"Houston TranStar continues to improve its operational effectiveness and expand its transportation and emergency management facilities and systems. Cooperative working relationships fostered by daily interaction of the staffs of various agencies in the region and frequent coordination and training meetings are invaluable to the operations of Houston TranStar" (Texas Transportation Institute 2005).

In addition to the freeway management systems, in the greater Houston area, there are more than 3,000 signalized intersections. The City of Houston plays a central role, operating and maintaining almost 2,400 signals in the city (City of Houston interview, 2005). In 2004, the City undertook the Traffic Signal Timing Optimization Project, which included 1,540 traffic signals, including three high employment centers – the Central Business District, the Texas Medical Center, and Uptown – and 86 corridors. Unusual for a transit agency, METRO has taken on a responsibility for deploying the Regional Computerized Traffic Signal System (RCTSS), which includes signal controller upgrading and interconnection back to TranStar for 1,225 signals, as well as adding Opticom transit signal priority for METRO’s vehicles. Originally, the RCTSS was to included full modernization for nearly 3,000 signals – including vehicle detection, timing optimization, fiber optics, American Disabilities Act (ADA) pedestrian compliance, transit signal priority, signal heads, and signal controllers – although the actual implementation of this modernization package has been more limited. Yet, because the CMAQ funding came through Federal Transit Administration (FTA), signal priority was incorporated using Opticom technology, and deployment was focused along transit corridors. Harris County plays a smaller role in traffic management, with only about 500 signals (City of Houston and Klotz and Associates interview, 2005). However, the county is currently deploying communications links (fiber optic) to TranStar, and is adding arterial cameras, in large part with the use of CMAQ funds.
5.4.3.2 Transit

METRO is also linked into TranStar, where its communication center subsystem provides Computer Aided Dispatch (CAD) for all vehicles with Advanced Radio Communications Systems installed (PBS&J and Battelle 2003). From the TranStar facilities, METRO operates its bus dispatching, METRORail control center, HOV lane operation and incident management, and monitoring and operation of park and ride facilities (Texas Transportation Institute 2005, p 20).

In terms of in-vehicle systems, the Integrated Vehicle Operations Management Systems (IVOMS) consists of a number of ITS technologies such as automatic vehicle location (AVL), automatic passenger counters (APC), mobile data terminals, and bus annunciators for in-vehicle stop announcements. Also, as discussed above, METRO has also been involved in the signal upgrading efforts, which have included transit signal priority based on Opticom, which is a partially manual system in that bus drivers must request signal priority by flashing their headlights at RCTSS/Opticom-equipped intersections. This set of technologies, when fully deployed, will provide for improved operations and passenger service.

5.4.3.3 Information and Other

TranStar again is the hub of activity for traveler information, primarily through its traveler information website, dissemination of content to broadcast media, and other personal alert methods. In 2004, there were over 99 million accesses to the website, with an average of 162,814 users each month (Texas Transportation Institute 2005, p 11). This indicates an average of over 50 accesses per user per month, meaning that not only is the website used widely, but also used intensively by each user on average. TranStar has also been innovative in its delivery of traveler information, with a web-based traffic map, email notifications, and delivery of information to cellular phones and personal digital assistants (PDAs). The DMS are also employed on a regular basis, automatically providing detailed travel time information gathered from the AVI reader checkpoints. In addition to the information on travel times, the DMS are also operated for incidents, road closures, weather incidents, Amber Alerts,\(^{137}\) special events, and Ozone Alerts (Texas Transportation Institute 2005, p 5).

According to the Regional Transportation Plan, METROVan, part of the Commute Solutions program managed by H-GAC in cooperation with METRO, is the fourth largest vanpool program in the nation (Houston-Galveston Area Council 2005, p 13). Beginning in 1994, with 50 vanpools, it currently serves 400 vanpools with approximately 5,000 commuters (Metropolitan Transit Authority of Harris County (METRO) 2004). The vanpooling and carpooling programs are supported by a web-based system for matching potential rideshares. The METRO online carpool and vanpool matching database has made over 7,300 “matches” since the system came online in February 2004 (Metropolitan Transit Authority of Harris County (METRO) 2004). Building upon its experience with HOV-lane management, METRO also operates the QuickRide program, which is part of the FHWA Value Pricing Program.

\(^{137}\) State-authorized information on missing children.
As noted earlier, the occupancy levels of Houston’s HOV network have often been adjusted to maintain high levels of service while utilizing the HOV lanes more fully. The QuickRide program, which was first launched on the Katy Highway HOV in 1998, enabled two-person carpools to “buy” the excess capacity (for $2), thus converting it into a high occupancy/toll (HOT) lane. In 2001, HOT lane operations were extended to the US 290 during the morning peak. In fact, as noted in the TranStar annual report, “as of 2004, Houston had two of the four operating HOT lanes in the nation” (Texas Transportation Institute 2005).

5.4.4 ITS-Air Quality Links

According to the Houston TranStar Annual Report 2004, since its opening in 1996, the travel time savings provided through improved transportation management has saved almost 23.3 million gallons of gasoline, 503 tons of VOC, 3,250 tons of CO, and 731 tons of NOx (Texas Transportation Institute 2005, p 28). Very few opportunities are missed to highlight the possible air quality improvement generated by Houston’s ITS deployments. According to the Houston Region ITS Strategic Plan, for example, more than half of the deployment concepts/projects are expected to have fuel consumption and emissions benefits (PBS&J and Battelle 2003). While one could initially dismiss these claims as rhetoric on the part of agencies wishing to bolster support for ITS applications, looking more closely at the transportation and air quality planning process, it becomes clear that ITS and short-term emission reductions are indeed tightly connected in the Houston area. Evidence of this can be seen in the Transportation Control Measures incorporated in the SIP, the use of CMAQ funds for ITS, and the effort that has been made to evaluate the emissions impacts in a consistent manner through the development of the MoSERs manual.

5.4.4.1 Projects

When looking at some of Houston’s cornerstone ITS deployments and TCMs, one finds substantial overlap. In the 2000 conformity attainment demonstration for Houston, three categories of TCMs have an important ITS component: ITS, the Regional Computerized Traffic Signal System (RCTSS), and, albeit to a more limited extent, Transportation Demand Management (TDM) strategies. Projects under the categories of both ITS and RCTSS are primarily arterial signalization projects, involving installation, synchronization, interconnection, as well as linking the traffic signals back to TranStar, so that signals can be monitored and updated remotely and in real time. Transportation demand management (TDM) measures include telecommuting, vanpooling and other commuting alternatives. ITS is utilized for the vanpooling program, managed by H-GAC and METRO, through the online vanpooling resources for matching vanpoolers and finding available openings or accessing waiting lists for existing vanpools.138

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138 It is notable that over half of the online mini-pools (smaller vanpool for 5-8 riders) have waiting lists for new members. See www.urbantrans.com/minipool/minipool_currentvans.html. Last accessed December 18, 2005. See www.vanpool.org for information on the Commute Solutions program, vanpools and minipools.
When comparing NOx emissions reductions and total project cost across different TCM categories (see Figure 5-11), ITS and RCTSS fare relatively well in terms of their cost efficiency. For example, the RCTSS provides approximately the same NOx reductions as bike and pedestrian projects, yet at a much lower cost. ITS measures, primarily traffic flow improvements in nature, generate reductions approximate to those of transportation supply measures – grade separations, interchanges, and left turn lanes – yet at one-fifth the cost of ITS. However, it is important to note that the RCTSS and ITS calculations do not attempt to measure induced demand from travel time improvements. Therefore, the reductions from the RCTSS and ITS measures could be overestimated. The relative cost and emissions performance of TCMs can be seen in Table 5-7 for measures completed or pending after 2000.
Table 5-7 Number of projects, emission reductions, and cost by project type (after 2000)

<table>
<thead>
<tr>
<th>Project Type</th>
<th>No. of Projects</th>
<th>Share (%)</th>
<th>VOC Emissions (kg/day)</th>
<th>% of VOC</th>
<th>NOx Emissions (kg/day)</th>
<th>% of NOx</th>
<th>Project Cost (Millions)</th>
<th>% of Total Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bicycle/Pedestrian</td>
<td>46</td>
<td>34%</td>
<td>48.7</td>
<td>12%</td>
<td>70.3</td>
<td>10%</td>
<td>$77.5</td>
<td>11%</td>
</tr>
<tr>
<td>Intermodal</td>
<td>2</td>
<td>1%</td>
<td>3.9</td>
<td>1%</td>
<td>6.8</td>
<td>1%</td>
<td>$18.8</td>
<td>3%</td>
</tr>
<tr>
<td>ITS</td>
<td>24</td>
<td>18%</td>
<td>71.3</td>
<td>17%</td>
<td>126.3</td>
<td>19%</td>
<td>$56.4</td>
<td>8%</td>
</tr>
<tr>
<td>Park and Ride</td>
<td>10</td>
<td>7%</td>
<td>34.2</td>
<td>8%</td>
<td>48.3</td>
<td>7%</td>
<td>$14.2</td>
<td>2%</td>
</tr>
<tr>
<td>RTSS</td>
<td>16</td>
<td>12%</td>
<td>30.1</td>
<td>7%</td>
<td>66.2</td>
<td>10%</td>
<td>$15.9</td>
<td>2%</td>
</tr>
<tr>
<td>TDM</td>
<td>6</td>
<td>4%</td>
<td>146.8</td>
<td>35%</td>
<td>206.8</td>
<td>31%</td>
<td>$15.7</td>
<td>2%</td>
</tr>
<tr>
<td>TDM (Transit)</td>
<td>2</td>
<td>1%</td>
<td>15.0</td>
<td>4%</td>
<td>21.2</td>
<td>3%</td>
<td>$301.3</td>
<td>44%</td>
</tr>
<tr>
<td>TSM</td>
<td>31</td>
<td>23%</td>
<td>69.5</td>
<td>17%</td>
<td>128.6</td>
<td>19%</td>
<td>$178.9</td>
<td>26%</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>137</strong></td>
<td><strong>100%</strong></td>
<td><strong>419.44</strong></td>
<td><strong>100%</strong></td>
<td><strong>674.55</strong></td>
<td><strong>100%</strong></td>
<td><strong>$678.5</strong></td>
<td><strong>100%</strong></td>
</tr>
<tr>
<td><strong>ITS TOTAL</strong></td>
<td><strong>40</strong></td>
<td><strong>29%</strong></td>
<td><strong>101.42</strong></td>
<td><strong>24%</strong></td>
<td><strong>192.47</strong></td>
<td><strong>29%</strong></td>
<td><strong>$72.3</strong></td>
<td><strong>11%</strong></td>
</tr>
</tbody>
</table>

Source: Appendix 9.14 (Houston-Galveston Area Council 2005)
Includes projects completed/pending after 2000
(and replacement projects for withdrawn TCM commitments).

Of all of the TCMs, the transportation demand management (TDM) strategies are the most effective and efficient. The presence of a large HOV network in Houston may explain the effectiveness of TDM strategies, since carpooling and vanpooling can provide substantial travel time savings. This also points to the possibility of scale effects in certain TDM strategies, where use of HOV lanes and carpooling increases exponentially as the size of the network grows. In the upper right corner of Figure 5-11 are two transit projects: a smaller project for the purchase of alternative fuel vehicles, and a $300 million, 7.5-mile light rail project connecting the central business district and the Texas Medical Center (past 610) implemented by METRO, a TCM which was added in the December 2000 SIP. The emission reductions from this measure are among the lowest, and at a substantial cost.

ITS has also been incorporated as VMEPs, which are similar to TCMs put applied on a voluntary basis to avoid the administrative issues with documenting the "timely implementation" of TCMs. For example, additional measures under the Commute Solutions program for transit and ridesharing are included, additional signalization improvements through the RCTSS program, and the smoking vehicle program which supports the reporting of smoking vehicles to the Texas Commission on Environmental Quality. 139

Earlier TCMs, implemented between 1994 and 1999, show some interesting comparisons with more current TCMs. We can see that the share of spending on ITS and RCTSS (81%) was substantially larger between 1994 and 1999, while there were only a few minor TSMs, mostly in the form of right turn lanes. The current list of TCMs (projects implemented after 2000) greatly expands spending on capital projects for both transit and TSMs. Indeed, there were no transit

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139 A notification is then sent to the owner of the vehicle, requesting a voluntary inspection and repair of the vehicle. There is no mandatory action required of the owner. Vehicles can be reported by other drivers via a 1-800 number or through an online reporting form.
projects in the earlier list of TCMs (see Figure 5-12 and Table 5-8). Transportation demand management (TDM) programs, mainly the commute alternatives and regional vanpool program, were the most cost effective measure available during both periods. There was also some expansion of that program in terms of funding.

**Figure 5-12 Emissions reductions and total cost for TCMs (1994-9)**

![Emissions reductions and total cost for TCMs (1994-9)](image)

*Source: Appendix 9.14 (Houston-Galveston Area Council 2005)*
*Includes projects completed between 1994 and 1999.*

<table>
<thead>
<tr>
<th>project type</th>
<th>no. of projects</th>
<th>VOC (kg/day)</th>
<th>NOx (kg/day)</th>
<th>total cost (millions)</th>
<th>% of cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>BIKE/PED</td>
<td>4</td>
<td>13.9</td>
<td>25.4</td>
<td>$13.91</td>
<td>14%</td>
</tr>
<tr>
<td>ITS</td>
<td>16</td>
<td>45.0</td>
<td>88.3</td>
<td>$55.19</td>
<td>57%</td>
</tr>
<tr>
<td>RCTSS</td>
<td>74</td>
<td>132.6</td>
<td>108.3</td>
<td>$22.45</td>
<td>23%</td>
</tr>
<tr>
<td>TDM</td>
<td>3</td>
<td>86.0</td>
<td>121.1</td>
<td>$2.44</td>
<td>3%</td>
</tr>
<tr>
<td>TSM</td>
<td>6</td>
<td>3.2</td>
<td>4.2</td>
<td>$2.14</td>
<td>2%</td>
</tr>
<tr>
<td>TOTAL</td>
<td>103</td>
<td>280.7</td>
<td>347.3</td>
<td>$96.14</td>
<td>100%</td>
</tr>
</tbody>
</table>

*Source: Appendix 9.14 (Houston-Galveston Area Council 2005)*
*Includes projects completed between 1994 and 1999.*

One should not overstate the actual emissions reductions from TCMs, which count for only a small percentage of necessary emissions reductions to meet the mobile source emissions budget.
Nonetheless, TCMs are an important component of SIPs from a regulatory standpoint, and can keep areas that are borderline from confronting conformity problems.

5.4.4.2 Funding

CMAQ has been an important funding source both for air quality and ITS initiatives. In describing the connection between the two, an interviewee from H-GAC summarized it as the following:

"ITS and CMAQ are helpful, but they’re not the white knight coming in to save us from air quality problems…. it’s a supporting role, and a happy factor when it can contribute to both our air quality goals and our mobility goals." (H-GAC interview, 2005).

Because of its designation as severe non-attainment for ozone, Houston receives a large influx of funding through the CMAQ program. For example, from fiscal years 1996 to 2000, $196 million in CMAQ monies were spent on projects let to contract (Transportation Research Board 2002, p 250). CMAQ funds have been an important source of funding for ITS initiatives, for example, providing between $1-2.5 million in annual funds for TranStar, although this varies from year to year depending upon what projects are currently being funded through CMAQ (TranStar interview, 2005). This represents an important proportion of the operating costs of TranStar, which are roughly $3.2 million each year. Looking at the 2004 TranStar Annual Report, nearly half of the systems operated through TranStar lists the CMAQ program as one of the funding sources. Early funding for TranStar came from federal earmarks, primarily the ITS Priority Corridor program. However, as these funds ran out, CMAQ funds helped finance both building construction and operations as the earmark expired (Transportation Research Board 2002, footnote 41). As noted by a TranStar interviewee, “bad air is not always a bad thing in the funding area – we would be in a lot of trouble if we didn’t have CMAQ funds” (TranStar interview, 2005).

In terms of the breakdown of CMAQ funding categories, ITS-based improvements predominate in the current TIP, in terms of both number of projects and share of total CMAQ funding, with 27% of the $306 million in CMAQ funding for projects for TIP years 2005-2008 (see Table 5-9). This seems consistent with earlier patterns of CMAQ spending. Between fiscal years 1996 and 2000, nearly 60% of CMAQ funding went to traffic flow improvements – ITS projects such as RCTSS and TranStar facilities were included within that broader category (Transportation Research Board 2002, pp 249-250 and Table D-5).

140 Projects with CMAQ as one of the funding sources include: TranStar center, fiber optics, CCTV, AVI, DMS, HAR, flow signals, and RCTSS.
141 The $306 million includes both federal funding and the required local match. The federal portion of CMAQ funding would be approximately $250 million.
142 We have included ITS projects as a separate category. Earlier reporting on CMAQ included ITS within the category of traffic flow improvements.
Table 5-9  CMAQ project categories for Houston, TIP years 2005-2008

<table>
<thead>
<tr>
<th>Project Category</th>
<th>No. Projects*</th>
<th>CMAQ Cost (millions)</th>
<th>Total Cost** (millions)</th>
<th>Share of all CMAQ funds</th>
<th>VOC (kg/day)</th>
<th>NOx (kg/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ITS</td>
<td>37</td>
<td>$ 82.05</td>
<td>$ 81.38</td>
<td>27%</td>
<td>290</td>
<td>456</td>
</tr>
<tr>
<td>Bike/Pedestrian</td>
<td>17</td>
<td>$ 29.07</td>
<td>$ 32.26</td>
<td>10%</td>
<td>114</td>
<td>68</td>
</tr>
<tr>
<td>Traffic Flow Improvements</td>
<td>13</td>
<td>$ 66.23</td>
<td>$ 714.69</td>
<td>22%</td>
<td>18</td>
<td>28</td>
</tr>
<tr>
<td>Other (Clean Vehicles/</td>
<td>6</td>
<td>$ 73.63</td>
<td>$ 73.63</td>
<td>24%</td>
<td>860</td>
<td>1,177</td>
</tr>
<tr>
<td>Fuels, Outreach)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TDM</td>
<td>5</td>
<td>$ 22.50</td>
<td>$ 22.50</td>
<td>7%</td>
<td>72</td>
<td>101</td>
</tr>
<tr>
<td>Park &amp; Ride</td>
<td>4</td>
<td>$ 8.55</td>
<td>$ 8.55</td>
<td>3%</td>
<td>18</td>
<td>25</td>
</tr>
<tr>
<td>Transit</td>
<td>2</td>
<td>$ 23.66</td>
<td>$ 23.66</td>
<td>8%</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>TOTAL</td>
<td>84</td>
<td>$ 305.69</td>
<td>$ 956.57</td>
<td>100%</td>
<td>1,370</td>
<td>1,855</td>
</tr>
</tbody>
</table>

Includes all projects listed for TIP years 2005-2008, excluding contingency projects.

Source: (Houston-Galveston Area Council 2005, Appendix H)

In terms of how these project categories compare in their relative cost-effectiveness for emissions reductions, we look at the total NOx reductions and amount of CMAQ funds programmed for these projects (see Figure 5-13). It should be noted that this figure shows only the federal CMAQ portion, and does not include the state or local contribution, which must be at least 20% of total project cost. Bike/pedestrian, Park and Ride, and TDM strategies appear as relatively cheaper projects, but with small emissions reduction potential. Traffic flow improvements cost significantly more, with $66 million in CMAQ and a much higher total cost of $715 million. ITS has the most number of projects, and the highest amount of CMAQ funding, and compares relatively well in its emission reduction potential. However, it does not compare nearly as well with the “Other” category, which achieves its emissions reductions primarily through clean vehicle and alternative fuel programs.

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143 “CMAQ cost” represents the total amount programmed in CMAQ funds for the project, which is usually 80% federal funding and 20% local match funds (thus, projects usually have more than one funding source). “Total cost” is the latest estimated cost, and may be lower than the authorized amount. Some projects may have the somewhat anomalous outcome that the “CMAQ cost” may actually higher than the “total cost.” This happens when the project is entirely funded through CMAQ and the latest estimated cost is lower than the amount authorized.

144 Emissions reductions calculations for the category of transit were not provided.
Not all stakeholders in the region agree with the manner in which CMAQ funding is used by Houston transportation agencies. A local non-governmental organization – Galveston-Houston Association for Smog Prevention – has criticized the use of CMAQ funds, noting that “these scarce dollars are often spent on freeway interchanges and other road projects disguised as ‘congestion mitigation,’” and pointing to the need to fund more bicycling, transit and walking facilities that reduce VMT and therefore improve air quality and congestion.\(^{145}\) Their assessment is correct in identifying the relatively poor cost-effectiveness performance of traffic flow improvements from the viewpoint of emission reductions. For example, in the 2006-8 TIP, this category uses 22% of total CMAQ funds, while generating only 1.3% of NOx and 1.5% of VOC reductions (see Table 5-9). However, beyond this category, most of the CMAQ spending – ITS, Park and Ride, Bike and Pedestrian – performs relatively well. Furthermore, most interviewees in Houston note they judge CMAQ projects both on their emission reductions as well as congestion mitigation benefits, a view that was also reflected in the 10-year CMAQ Program review undertaken by TRB (TxDOT, H-GAC interviews, 2005).

The same agencies that cooperate closely through TranStar, also compete for CMAQ funds. Although TxDOT and METRO have tended to sponsor the majority of CMAQ funded projects, the City of Houston and Harris County to a lesser extent also recommend projects (Transportation Research Board 2002, p 245). In addition to these four agencies, there are also numerous cities and eight counties in total competing for CMAQ funds. Competition for funding, which to some extent reflects agency competition for “turf”\(^ {146}\) can be seen in the case of


\(^{146}\) We use the term “turf” to refer to bureaucratic organizations’ missions, responsibilities and boundaries, as described by Wilson, J. Q. (1989). *Bureaucracy: What Government Agencies Do and Why They Do It*, Basic Books.
traffic signalization projects undertaken by METRO and by the City of Houston. The City of Houston is responsible for managing the operation of nearly 2,400 signalized intersections within the city's jurisdiction. Currently, a bulk of the City's ITS efforts are funded through CMAQ. After several years of negotiation with TxDOT, the City secured CMAQ funds for work on 30 signalized corridors, consisting of optimization, modification, and installation, and including elements such as video detection, signal heads, pedestrian ADA compliance, and cabinet controllers as well as before-and-after studies (City of Houston interview, 2005). In addition, some of the signals optimized as part of the Mayor's Traffic Signal Timing Optimization Plan (TSTOP), were supported with CMAQ funds. However, the multi-faceted transit agency, METRO, also secured funding through CMAQ for signal improvements through the RCTSS program. Therefore, while “METRO is deploying the extensive RCTSS network for the benefit of Houston TranStar’s traffic management agencies” (Texas Transportation Institute 2005), some of the other agencies are skeptical about whether METRO has any role to play in operations once the system is in place, noting that they are primarily a transit agency, not traffic signal engineers. Furthermore, delays in deploying the system in interconnecting the system, also affected the City of Houston, who instead of programming signals from TranStar using the RCTSS infrastructure, decided to move ahead with a rapid program of manual programming of the signals through TSTOP.149 In summary, the interdependence between agencies is strong, both in terms of cooperation in deploying and upgrading the signal systems, and competition, with competition for funding sources such as CMAQ and their respective roles in the operation of the traffic signal network.

In addition to the CMAQ program, funds from the Surface Transportation Program (STP) have also been used increasingly for operations. Some interviewees looked toward the model of Florida, where “set-asides” of STP are designated to operations projects such as ITS (TranStar interview, 2005). However, because STP funds do not have the restrictions on use as CMAQ funds do, they must compete with roadway projects. Annual set asides for operations-only projects do not appear to be a realistic near-term option, particularly in Houston given the strong population growth and demand for infrastructure expansion. For this reason, CMAQ funds remain an important source of funding for ITS. In the absence of CMAQ funding, some ITS projects would have found alternate sources of funding, however, according to planners, many would have either been delayed or entirely cancelled (H-GAC interview, 2005). Furthermore, in the absence of CMAQ funds, the most affected ITS projects would probably be those undertaken by the cities and counties, since they are more limited in their ability to access alternative sources of funding, than say, TxDOT or METRO.

147 The emissions from these traffic signal optimizations were incorporated in Houston's conformity determination under the category of Transportation Emissions Reduction Programs (TERMs), which was described above.
148 Basically, the operations that will be conducted at the traffic signal control station (using the I-2 software platform) at TranStar.
149 “Mayor Bill White made it clear he wasn’t going to wait for Metro to complete the RCTSS before putting some of its components to work. The mayor’s first initiative after taking office in January was laying out a yearlong effort for public works to manually program more than 1,500 traffic signals.” Source: Lucas Wall, “Signal system hits more snags,” The Houston Chronicle, December 19, 2004, page A1.
5.4.4.3 Evaluation

Generally, the organizations that use CMAQ funds do not do the evaluations of the air quality benefits. This responsibility falls primarily on planners at H-GAC, supported by researchers at the Texas Transportation Institute and other academic institutions, with the operating organizations providing the raw data. TranStar, during its start-up days, was able to undertake analysis and other research activities in-house, because it had not yet become fully operational and had the flexibility to do more analysis. However, once operational, those activities had to be shifted to outside H-GAC and others (TranStar interview, 2005).

The Texas Transportation Institute (TTI) has played a critical role in filling the evaluation needs for linking ITS deployment and mobile source emissions reduction strategies. Most notably, TTI developed the “Texas Guide to Accepted Mobile Source Emission Reduction Strategies,” more commonly referred to as the MoSER handbook. This guide is intended to “aid technical staff to assess the benefits of SIP elements, conduct transportation conformity analysis, and initiate proactive emission reduction programs to fulfill national air quality standards” (Texas Transportation Institute 2003, p xi). In addition to providing general background on transportation and air quality planning, this handbook provides basic equations for each measuring the emission changes from each individual control measure including, but not limited to, ITS. Although more sophisticated software packages for modeling are discussed, the handbook suggests the use of their sketch-planning techniques which are easier to apply and less “cumbersome” for use in the interagency review process required for SIP development (Texas Transportation Institute 2003, p B.1.2). The mobile source emissions reduction strategies are divided into 17 categories, the most important of which for ITS is the category of traffic flow improvements, which covers traffic signalization, traffic operations, enforcement and management (incident management, ramp metering), freeway management, and railroad grade separation.150 Most of the equations for traffic flow improvements use changes in speed-based running exhaust emissions factors (grams/mile) – before and after the measure is implemented – combined with length and traffic volumes of the affected facilities (VMT) to give total emissions changes. Other equations – such as ramp metering and individual intersection improvements also incorporate reductions in idling emissions. Although the issue of induced travel is raised with respect to several measures, it is not incorporated in the equations used for calculation emissions changes.

“Traffic signalization improvements may encourage additional traffic, increasing VMT. An increase in VMT along a roadway with improved traffic flow would offset some of the short-term air quality improvements generated by faster, more consistent travel speeds. Also, by reducing travel time on affected corridors, traffic signalization may attract additional vehicles and divert motorists from alternative modes of transportation” (Texas Transportation Institute 2003, p B.7.4).

150 The other 16 categories are: improved public transit, high-occupancy vehicle facilities, employer-based transportation management programs, trip-reduction ordinances, park-and-ride/fringe parking, vehicle use limitations/restrictions, area-wide rideshare incentives, bicycle and pedestrian programs, extended vehicle idling, extreme low-temperature cold starts, work schedule changes, activity centers, accelerated vehicle retirement, parking management, vehicle purchases and re-powering, and congestion pricing.
To take an example, the MoSER handbook was used to calculate emissions for the City of Houston’s signal timing improvements—a measure included in the 2005 conformity determination as a TERM. Before-and-after speed studies done by the City of Houston indicated a speed improvement from 25 to 30 mph (approximately 20%), typical for a traffic signalization project. However, in calculating emissions for the affected links, induced travel was not incorporated. Average volumes and VMT were instead kept constant, since according to H-GAC, “there is no data upon which to base estimates of altered volumes that could result from changes in speed” (Houston-Galveston Area Council 2005, Appendix 9.18). Because induced demand is difficult to estimate or measure, it is typically ignored.

In addition to not addressing the induced demand issue in a satisfactory way, the MoSER handbook does not allow for the consideration of system effects, such as the possible synergies or conflicts between different ITS applications, and long-term effects, such as induced travel. However, MoSERs does provide a consistent and clear methodology to make comparisons for a range of different emissions reductions strategies, and to document those emissions reductions for regulatory purposes.

Evaluation of the air quality benefits of ITS has also been an important component of TranStar’s Annual Report, as discussed earlier, and the cumulative emissions reductions (calculated directly from fuel savings) are reported annually. The Annual Report does not use the MoSERs recommended methodologies for reporting emissions reductions. Yet, when reporting on individual components, especially for CMAQ-funded components, the MoSER equations are used.

5.4.5 Summary

Looking beyond its reputation as a city that rejects planning, builds highways with fervor, and ignores air quality concerns, Houston is a substantially more complex case in terms of its strategies to deal with both transportation and air quality issues. While Houston continues to pursue highway expansion, it has also been more aggressively pursuing transit options, HOV and ITS. Highway expansion seems to be slowing, with diminishing returns for additional highway miles. As noted in an interview with a TranStar representative, the “cheap options” are gone, and right-of-way costs are now half of total project costs (TranStar interview, 2005). Major projects such as the Grand Parkway third beltway loop on the outskirts of Houston, continue to move forward, albeit slowly. This observation echoes Altshuler and Luberoff, who have noted that while some states in the post-megaproject era are continuing to build expressways, they are “almost exclusively in fringe areas,” citing beltways in Houston and Denver and a major connector in Atlanta (Altshuler and Luberoff 2003, p 277). Yet, they also add that those beltway-type projects are often challenged on the basis of induced travel, sprawl and air quality impacts. Houston is a clear case of that pattern of cost escalations for projects in already built-out areas, and environmental challenges for projects on the “fringe” of metropolitan areas.

In terms of competing with infrastructure, ITS has been seen more as a “delaying tactic,” more so than a true alternative to physical expansion (H-GAC interview, 2005). Returning to the example of the Grand Parkway project, some interviewees cited delays in that project and others
as part of the congestion problem in Houston, given the growth in population and VMT, and suggest that until that infrastructure can be built and relieve traffic congestion, ITS can be used in the meantime to mitigate congestion (TranStar interview, 2005). However, to say that ITS can be a substitute for physical infrastructure, “would be going too far” (TranStar interview, 2005).

In terms of air quality conformity, ITS has played an increasingly prominent role as mobile source emissions reductions strategies, whether incorporated as TCMs, VMEPS or TERMS. In Houston, CMAQ funds have been an important source of funding for ITS projects, and ITS projects have been an important source of emissions reductions in air quality plans. This reflects in large part the approach to air quality management in Houston. For example, the SIP is more of a flexible document with nearly constant revisions, than a one-time planning effort. The revisions in the Houston-Galveston sections of the Texas SIPs have reflected rapid responses to both new scientific findings on sources and formation of ozone and pressures from interested and affected groups for modification or elimination of certain measures. Furthermore, rather than regulating behavior, the trend in Houston has been to make gains in emissions reductions whenever possible with technology, and ITS is consistent with that framework, by reducing transportation related emissions without constraining driver behavior.

Houston’s experimentation with ITS for air quality purposes has been facilitated by the development of consistent assessment techniques using the MoSERs handbook. Indeed, of all case study cities, Houston has been the most aggressive in experimenting with the use of ITS as a tool for both emissions reductions and mobility improvements, and building upon evaluations of air quality benefits in future ITS deployments. Therefore, while the rhetoric is pervasive in terms of the air quality benefits of ITS – for example, looking at the 1994 Strategic Plan, the 2003 Strategic Plan and Regional Architecture, and TranStar’s Annual Reports – the tools for evaluation provided through the MoSER handbooks and accompanying modules has allowed ITS project promoters to defend their air quality claims with data. The potential problem is the omission of consideration of induced demand.\footnote{In the MoSERs handbook, there are numerous caveats as to the possibility of induced trips and VMT from transportation system improvements, including for ITS; yet it does not provide methods to estimate the extent of those impacts.}

The core strength of Houston’s ITS program is in freeway management, and that is where most of the air quality benefits of ITS are found. In more recent years, transit systems have also come to the forefront, with the deployment of the first light rail and METRORail, growing ridership levels on METRO’s bus network, and the deployment of advanced transit management systems such as IVOMS. But, public transit ITS strategies have yet to be fully incorporated in Houston’s air quality plans and emissions reductions measures, because of difficulties in estimating and documenting the impact that ITS can have on emissions via changes in mode share.

Houston works well within the framework of air quality standards and transportation conformity, as established by the CAAA and ISTEA, in a manner that attempts to minimize the impact on economic growth and on individual behavior. Yet, its Achilles’ heel may be the issue of longer-term environmental sustainability, where national standards and programs do not
exist. Houston effectively uses ITS as a measure for congestion relief and near-term reductions in ozone precursor emissions. Yet, concerns regarding the system-wide and long-term impacts of induced travel have not made its way into either the evaluation process or, apparently, the decision-making process. Nevertheless, recent trends in transit systems and ridership, as well as experimentation with HOT lanes and other demand management strategies, may indicate a growing trend toward strategies to reduce VMT using the support of ITS technologies.

\[152\] For example, considering issues such as greenhouse gas emissions or air toxics.
5.5 LOS ANGELES, CALIFORNIA

5.5.1 Background

5.5.1.1 The City

The Los Angeles region is remarkable in its size. Considering Los Angeles as all of southern California, excluding San Diego, the six-county region is home to more than 17 million people, according to 2003 figures, meaning that approximately six percent of the entire US population resides in the area (Southern California Association of Governments 2004, p 35). In economic terms, the region by itself would be the tenth largest economy in the world. The map shown in Figure 5-14 reveals both the size and complexity of the Los Angeles region, and the vast number of communities – 187 cities in total – encompassed within the region (Chang 2005, p 5).

During the early 1990s, Southern California fell into a severe recession that affected the rate of both economic and population growth (primarily between 1991 and 1995) recovering briefly until 2001, when there was a sharp downturn the national economy. Since 1999 the region has experienced high levels of population growth not seen since the 1950s, due to natural population increase (49% of population growth), and net foreign immigration (40%) and net domestic immigration (11%). Between 2000 and 2004, average annual population growth was high with the addition of 320,000 residents each year (Chang 2005, p 18). Continued growth in the population and geographic size of the region is expected, with urbanization continuing to push out from the wealthier and denser areas in the Los Angeles Basin, northern Orange County and the coastal areas, and moving toward the desert and mountains, and filling in what is referred to as the “Inland Empire” of Riverside and San Bernardino counties (SCAG interview, 2005).
Figure 5-14 Map of Los Angeles Metropolitan Area

Source: www.mapquest.com
A.1.1.1 Transportation

Martin Wachs, a longtime observer of transportation policy, politics and planning in Los Angeles, made the following observation in a speech at University College in London.

"Just as the Eiffel tower comes to mind as the symbol of Paris, and the Statue of Liberty symbolizes New York, the international recognized symbol of Los Angeles is the freeway. Los Angeles is known the world over as the prototype city of the late twentieth century by both its critics and its detractors, and its very essence is to be found in its transport system as well as its far flung mix of low and moderate density communities connected by thousands of miles of high capacity freeways.... It is obvious that transport systems have been a central object of policy makers throughout the evolution of Los Angeles" (Wachs 1993, p.3).

The map in Figure 5-14 gives a sense of the size and complexity of the network – 9,000 lane miles of freeway and 42,000 lane miles of arterials. Wachs also suggested at that time that Los Angeles was in the midst of its "third major transport crises of the twentieth century," where transportation and traffic issues are the top of the agenda for the region, with intense attention from both the public and officials in the region.153 Indications suggest that the crisis has by no means subsided since Wachs’ description over ten years ago, and has now overlapped into the next century to become the first major transport crises of the twenty-first century for Los Angeles. Indeed, the situation on the face seems to have changed little. Between 1993 and 2003, Los Angeles and Orange Counties consistently ranked as the highest in the nation for congestion delay (Chang 2005, p 11). While congestion has continuously been ranked as the worst in the US for Los Angeles and Orange Counties for at least the past decade, the positive side is that absolute levels of congestion have not increased at the same rate as other large metropolitan areas in the US (with a travel time index of 1.75 in 2003, compared to 1.73 in 1993).154 Yet, there are trends that the problem is worsening in other aspects. While absolute congestion levels are relatively stable in Los Angeles and Orange counties,155 the more problematic trend is to the east in San Bernardino and Riverside Counties, where traffic conditions are rapidly deteriorating, with an increase in the travel time index from 1.27 to 1.37 between 1993 and 2003 (Chang 2005, p 64).

Unlike the earlier transportation crises of the 1920s and post-World War II period, the current transportation crisis that began in the 1980s has generated a much different response, according to Wachs. Indeed, he suggests that the “recent change in direction in transportation policy is one of historic proportions,” as Los Angeles attempts to provide alternatives to the automobile

153 According to Wachs, the first transportation crisis in Los Angeles was in the 1920s when automobile ownership grew too rapidly for an inadequate local street system. The second crisis was when population growth and sprawl after World War II lead to traffic volumes that again “swamped” the surface street system Wachs, M. (1993). Learning from Los Angeles: Urban Form and Air Quality. Los Angeles, CA, Graduate School of Architecture and Urban Planning, University of California, Los Angeles: 30 pages.

154 The second most congested region is Chicago, with a travel time index of 1.57 in 2003, up from 1.34 in 1993.

155 Looking at the trends in TTI’s Urban Mobility Report, it is clear that keeping congestion at the same levels is a feat in itself, and reducing absolute congestion levels (as measured by hours of delay or the travel time index) is rare accomplishment, or the result of economic downturns in the region.
instead of increasing highway capacity to “accommodate its use” (Wachs 1993, p 5). He also adds that this change in direction was “quite self conscious.” Specifically, the new approach has utilized a combination of transportation demand management (TDM) measures, such as HOV lanes and carpooling and vanpooling programs and incentives, and major rail transit construction projects.\textsuperscript{156} This strategy has continued, with the 2001 and 2005 Regional Transportation Plans attempting to slow VMT growth in the region by focusing on reducing single occupancy vehicle (SOV) trips through transit, ridesharing, and telecommuting (Southern California Association of Governments 2004, p 53). However, the expansive freeway and arterial network has grown at a slower rate than both population growth and VMT growth, as seen in Figure 5-15.

\textbf{Figure 5-15 Growth in population, travel (VMT) and lane miles}

![Graph showing growth in population, travel (VMT) and lane miles](source)

\textit{Source: (Southern California Association of Governments 2004, p 54)}

Finally, in addition to the usual travel demands of people and goods for a major metropolitan area, Los Angeles also has the two largest cargo-handling ports in the US (the Port of Los Angeles and the Port of Long Beach), together forming the fifth largest maritime port complex in the world (Chang 2005, p 72). This substantial freight movement through the region is an important factor for economic competitiveness, congestion and air quality.

\subsection{Institutions}

The size and complexity of the Los Angeles metropolitan area is also reflected by its institutions responsible for transportation and air quality. As the designated MPO for the region, the Southern California Association of Governments (SCAG), formed in 1965, covers a six-county area, including Orange, Los Angeles, San Bernardino, Riverside, Ventura and Imperial Counties.

\textsuperscript{156} Wachs, in fact, criticizes these projects because of the high cost and small benefits, supporting alternatives such as the appropriate pricing of the automobile (to reflect its social externalities), land use policies, a wider range of transportation choices (such as jitneys or employer provided buspools) and new technologies, such as universal fare cards and real-time transit information.
SCAG’s Regional Council has 76 voting members that meet monthly, making it the largest council of government in the country. It also has a staff of more than 100 analysts and planners. SCAG is responsible for the long-term Regional Transportation Plan (RTP), which must be updated every three years, the Regional Transportation Improvement Program (RTIP), updated yearly, and transportation conformity assessments for the air quality management plan (AQMD).

Figure 5-16 Six-county SCAG region

In addition, all six SCAG counties have a commission or authority,\textsuperscript{157} which undertake planning for the county, allocate locally generated revenues, and operate transit services (Southern California Association of Governments 2004, p 29). However, the principal county-level players are the Orange County Transportation Authority (OCTA), Los Angeles County Metropolitan Transportation Authority (MTA or “Metro”), Riverside County Transportation Commission and San Bernardino Associated Governments.

In addition to SCAG and the County Transportation Commissions/Authorities, there are also 14 sub-regional councils of government which represent “groups of neighboring cities and communities (sometimes comprising an entire county) that work together to identify, prioritize and seek transportation funding for needed investments in their respective areas” (Southern California Association of Governments 2004, p 30). To coordinate between these sub-regional groups for air quality management, SCAG formed a Sub-regional Air Quality Planning, Analysis and Modeling Group (SAQ-PAM) – a type of middleman between the local governments and SCAG, created “to ensure that all possible efforts were being made to mitigate the air quality impacts of transportation” (South Coast Air Quality Management District 2003, p 68). Transportation and air quality planning and investment decisions are a multi-level process, but

\textsuperscript{157}Imperial County is somewhat of an exception, as transportation-related activities are carried out by the Imperial Valley Association of Governments (IVAG).
primarily a back-and-forth negotiation between the transportation commissions, local city
governments and subregional representatives, concerned with their local priorities, and SCAG,
which attempts to maintain regional consistency in their transportation investments and
improvements and stay within the air quality limits for conformity.

At the state level for transportation is the California Department of Transportation (Caltrans),
formerly, the California Division of Highways. Caltrans is divided in 12 districts for the state of
California, with each having responsibility for the design, construction, maintenance and
operation of the freeways within their districts. For the Los Angeles region, three different
districts have jurisdiction: District 7 for Los Angeles and Ventura counties, District 8 for San
Bernardino and Riverside counties, and District 12 for Orange County.

The most powerful state agency for air quality management in California is the California Air
Resources Board (CARB) created in 1967 as part of the California Environmental Protection
Agency. From its inception, CARB focused on improving air quality through controls strategies
heavily oriented toward mobile source emissions, as reflected in its early mission statement: "(1)
attain and maintain healthy air quality, (2) conduct research into the causes of and solutions to air
pollution, and (3) systematically attack the serious problem caused by motor vehicles, which are
the major causes of air pollution in the State." The first Chairman of CARB was Dr. Arie J.
Haagen-Smit, a professor of biochemistry at the California Institute of Technology, who first
discovered the processes of photochemical smog formation in 1952 (Molina and Molina 2002, p
7). Since that time, the eleven-member CARB Governing Board has continued to draw heavily
on expert representation, with five experts, five air quality district representatives and the
Chairman, all appointed by the governor. The CARB oversees all air pollution management and
control activities in California. However, in particular, they are responsible for motor vehicle
emissions, fuels and consumer products.

While in other states, mobile source emissions strategies are coordinated directly between the
MPO and state environmental agency, in the case of California, air quality is also managed by
“Districts”, which are regional air quality management organizations. There are 35 air quality
districts in the State of California, which are responsible for adopting local air quality
management plans and rules. The South Coast Air Quality Management District (SCAQMD) is
the district for the South Coast Air Basin, containing the largest metropolitan population in
California, with 14.7 million people in the 6,480 square mile area in 2000 (Alexis and Cox 2005,
p 114-5). SCAQMD covers four counties, including all of Orange County, and the majority of
Los Angeles County, and the western portions of Riverside and San Bernardino counties. In
coordination with SCAG, SCAQMD develops the Air Quality Management Plan (AQMP) for
local control strategies, such as TCMs, which are then incorporated in the State Implementation
Plan (SIP) for air quality. However, in addition to air quality planning and enforcement
functions, SCAQMD has also played an important regulatory role for mobile sources at the

159 The northeast and less urbanized portion of Los Angeles County falls under the Antelope Valley Air Pollution
Control District, while the eastern portions of San Bernardino and Riverside fall under the jurisdiction of the Mojave
Desert Air Quality Management District.
regional level – a feature perhaps unique to California. For example, under Health and Safety Code 40716, the District regulates large employers, considering them as “indirect sources” of emissions because of their impact on VMT. Therefore, they are required to implement mandatory ride sharing programs or equivalent mobile source emission reductions alternative programs (South Coast Air Quality Management District 2003, 7-1). SCAQMD is also responsible for control and permitting for local industrial sources and area-wide sources.

Public transportation service is provided by a number of agencies, although the L.A. County Metropolitan Transportation Authority (Metro) is the most prominent, operating the subway, light rail, bus rapid transit, regular fixed-route buses and paratransit. Metro also funds 16 municipal bus service providers. Metro is a large and powerful organization in the region, formed in 1993 when the Los Angeles County Transportation Commission merged with the Regional Transit District. This merger followed the 1992 approval by the L.A. County Transportation Commission of a $183 billion, 30-year plan for 400 miles of new rapid transit and commuter rail (Altshuler and Luberoff 2003, p 207). Metro now employs more than 9,200 people. Although Metro is multimodal in nature, including transit services (subway, bus, light rail, BRT), bikeway and pedestrian facilities, local road and highway improvements, and other projects, it is primarily known as a transit agency. Since the 1980s, Los Angeles has pursued an aggressive expansion of transit rail, including the Red subway line, and the Blue, Green and Gold light rail lines. MetroLink regional commuter rail is provided by the Southern California Regional Rail Authority.

The cities also have various degrees of transportation related activities related to local streets, such as arterial signal control. The City of Los Angeles’s Department of Transportation (LADOT) is by far the most active and advanced in both the traffic and transit arenas, operating transit services, and, as will be discussed below, developing some of the most sophisticated ITS applications for traffic signal control in the country.

Another organization that seems to play a role in linking transportation, air quality and advanced technologies, is the Southern California Economic Partnership (The Partnership), first proposed as part of the 1994 Air Quality Management Plan. This non-profit organization provides networking and guidance on the implementation and marketing of advanced transportation technologies, including many ITS applications. The Partnership has an 18-member Board of Directors composed of representatives from the public and private sector, including representatives from SCAG, SCAQMD, Caltrans and the county transportation commissions. According to SCAQMD documents, the Partnership has been “an active and effective entity” in supporting projects such as ITS, Smart Shuttles, Telecommuting Support, Alternative Fuel Vehicle Support and the Travel Advisory News Network (TANN) project (South Coast Air Quality Management District 2003, pp 23 and 26). Given the focus of this thesis, the Partnership would appear to be an important agent for innovation that integrates both congestion mitigation and emissions reductions goals. Yet, their actual impact on local transportation and air quality planning is unclear, indicated in part by the fact that none of the interviewees mentioned the Partnership once during the several hours of interviewing, despite its relevance to the topics discussed. One possible explanation is that agencies attribute the work not to Partnership itself, but to the individual actors that comprise it.
5.5.2 Air Quality History

The South Coast Air Basin (SCAB), designated as extreme non-attainment for ozone, finds itself at a major disadvantage in terms of its meteorological and geographic conditions – both of which conspire to produce extremely high levels of smog, as well as particular matter. Indeed, according to CARB’s annual emissions and air quality almanac “in terms of air pollution potential, there are probably few areas less suited for urban development” (Alexis and Cox 2005, p 114). The sunny conditions that characterize southern California unfortunately also promote the rapid formation of ozone, while ozone-forming emissions are continuously pushed back inland during the day by sea breezes (Molina, Molina et al. 2002, p 24). Coupled with these onshore sea breezes that push pollutants toward the mountains that border the basin inland, there are frequent low inversions effectively trap pollutants in the basin, creating stagnant conditions that foster ozone formation. Indeed, one can see from Figure 5-17, that some of the worst pollution occurs inland, in the counties of San Bernardino and Riverside.

**Figure 5-17 Geographic distribution of days exceeding 1-hour ozone concentrations**

Source: (South Coast Air Quality Management District 2003)

5.5.2.1 Sources

As an extreme non-attainment area, SCAB has until 2010 to meet national ambient air quality standards for 1-hour ozone. Not surprisingly, mobile sources are a predominant source of ozone precursors, particularly NOx. On-road mobile source emissions constitute about 60% of NOx emissions, with other mobile sources making up another 30% (see Figure 5-18). Stationary sources are a relatively small proportion of NOx, in large part because of switching to natural gas and installation of NOx control devices for electric utilities (Alexis and Cox 2005, p 116).

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\(^{160}\) SCAB is also in non-attainment for CO and PM10, although the focus here will be on ozone.
However, on-road mobile sources are also large contributors to VOC, even outweighing area-wide sources, which are the typical culprits for VOC emissions.

Figure 5-18 Emissions inventory for the South Coast Air Basin (2005)

Nevertheless, this represents a dramatic decrease in ozone precursors from earlier years. At the passage of the CAAA of 1990, NOx emissions averaged 1,588 tons per day, while VOCs averaged 1,775 tons per day (Alexis and Cox 2005, p 115, Table 4-1). These precursor emissions reductions are reflected in the downward trend in peak one-hour ozone concentrations and the number of days exceeding the ozone standard. As seen in Figure 5-19, maximum one-hour ozone concentrations were averaging well over 0.3 ppm in the mid- to late-1980s, and by the year 2000, that level had fallen to below 0.2 ppm. During that same time period, the number of days above the national 1-hour standard dropped from around 160 to 40, one-quarter of original number of exceedances.
While air quality has improved substantially over the past few decades, many NGOs in the region warn that it is too early to relax. For example, the National Resources Defense Council in Los Angeles, a powerful environmental lobbying group, has pointed out that the last five years have witnessed a steadily growing number of days above the one-hour standard – evidence that strong measures are still needed.\footnote{John M. Broder, “Cleaner Los Angeles Air? Don’t Hold Your Breath,” \textit{The New York Times}. November 14, 2004.}

5.5.2.2 Actions

Los Angeles has struggled with controlling air pollution for over 60 years, with 1943 marking the date of the first recorded photochemical air pollution episode in the city (Molina, Molina et al. 2002, p 23). Indeed, the Los Angeles Air Basin has literally been a laboratory for understanding the sources and process of ozone formation ozone. As a result, Los Angeles has been the national, if not world, leader for advances in air pollution science, control measures and programs, legislation and standards.

CARB has “traditionally seen itself as a technology-forcing agency” (Molina, Molina et al. 2002, p 31). CARB is unique because of California’s ability to set vehicle emissions standards stricter
than those set at the federal level by EPA.\textsuperscript{162} However, CARB cannot set fuel efficiency standards, which remains under the jurisdiction of the federal government, and even setting carbon dioxide emissions standards (which are directly proportional to a vehicle’s fuel economy) has been the basis for a number of legal battles with the automobile industry. In 1966, just before the official creation of CARB, California imposed regulations of tailpipe emissions that were “first of their kind in the US” (Molina, Molina et al. 2002, p 28). Since then, CARB has continued to adopt new standards and regulations for both vehicles and fuels, including two- and three-way catalytic converters, on-board diagnostic (OBD) systems, Low and Zero Emission Vehicle mandates, and regulations for reformulated gasoline. Indeed, it is generally recognized that the “most significant reduction in contaminant emissions has come from technological improvements in the automotive sector” (Molina, Molina et al. 2002, p 33). According to Caltrans, air quality improvements from mobile sources have mainly been from the reformulated fuels, emissions control devices, improving the durability of those devices, OBD, and lastly, the smog check program (Caltrans interview, 2005).

Nevertheless, the continued severity of the air pollution has lead to the increasing use of behavior-based strategies as well. One of the early and most notable of these transportation demand management strategies was Regulation XV, adopted in October of 1987 by the Board of SCAQMD, even before passage of the Clean Air Act Amendments of 1990 (Wachs 1993, p 14).\textsuperscript{163} Under Regulation XV, all public and private employers with 100 or more workers would have to create a plan for increasing the average vehicle ridership (AVR) for their employees, with AVR depending upon the location of the employer (i.e., in a high or low density area). In order to complement these programs and other ridesharing initiatives, Los Angeles has developed an extensive network of HOV lanes in order to provide travel time advantages to carpools and vanpools.

\textbf{5.5.2.3 Issues}

As noted by Wachs in the early 1990s, “reflecting concerns about air quality, energy, and the quality of life in the region, policy makers have in recent years rejected the strategy of increase highway capacity” (Wachs 1993, p 5). Indeed, most highway capacity increases are in the form of HOV lane addition\textsuperscript{164} or “gap closures” in the existing freeway network. Yet, even gap closure projects are difficult to implement. For example, the gap closure for Interstate 710, just north of Interstate 10, has been resisted by the communities of South Pasadena for decades.

\textsuperscript{162} Section 209(b) of the Clean Air Act grants California the authority to set its own emission standards as long as they are at least as stringent as the federal mobile emissions standards, while Section 177 allows other states to adopt California’s more stringent standards. Four northeastern states – Maine, Massachusetts, New York and Vermont – have all adopted California’s emissions standards.

\textsuperscript{163} Regulation XV had national repercussions in that it ushered in the Employee Trip Reduction mandate of the Clean Air Act Amendments – a mandate which would later by made a voluntary measure, left to the “discretion of the state.”

\textsuperscript{164} Caltrans has an “add-a-lane” policy for their HOV network development, meaning that they cannot take away an existing general traffic lane on the freeway for conversion to HOV (SCAG interview, 2005).
At the regional level the strategy has been to reduce VMT through this multi-pronged transit and TDM strategy, while at the state level, the focus is on introducing standards for cleaner fuels and vehicles. And, despite the frequently high costs of the transit and TDM measures meant to shift people from single-occupancy cars to transit and ridesharing, Los Angeles appears to be continuing along this path for air quality improvements. Yet, according to SCAG, even with these major investments in transit and carpooling, “it’s just keeping pace, and holding the percentage share... [at] 4 to 4.5% for transit, 16% for rideshare and carpooling, and the standard number is 80% for SOV” (SCAG interview, 2005).

In spite of the criticisms of many of the new transit projects (Wachs 1993; Altshuler and Luberoff 2003), and the difficulties in bringing down the share of single-occupancy vehicle trips, there does not seem to be much opportunity for backing away from this strategy, which has continually been “ratcheted up”. Indeed, many regional planners feel that this focus on transportation control measures – such as transit services and demand management – as a way to improve air quality, is skewed. According to one planner at SCAG:

“The reality is that 96-7% of the reductions that we have seen have come from improvements in tailpipe emissions, and 1% have come from TCMs. So the tail wags the dog” (SCAG interview, 2005).

Because many of the these measures have been incorporated into official air quality planning documents as TCMs, they represent stronger commitments, as they must be implemented on schedule to avoid conformity problems with EPA. The lock-in to these TCMs was evident with the recent budget shortfall in the State of California. As total levels of state funding fell, project funds were shifted around in order to cover the state portion of funding for all Transportation Control Measures, often moving funds to TCMs at the expense of other non-TCM projects that might be preferred by the county transportation commissions (SCAG interview, 2005).

While many have criticized what they see as an overemphasis of transit and demand management, this may have had a positive impact on ITS deployment. First, ITS has been used to support and enhance many of the new transit systems that have come into service in the past 10-15 years. In addition, the constraints on building new physical capacity have opened up opportunities for the deployment of ITS system to address the high levels of congestion in the region. As noted in many of the planning documents, with no room to expand, better system management becomes the dominant strategy, with ITS being a key component in system management. We will now discuss the deployment of ITS in Los Angeles.

\[165\] The term “ratcheting-up” is used by Vogel, D. (1993). Representing Diffuse Interests in Environmental Policymaking. Do Institutions Matter? R. K. W. a. B. A. Rockman. Washington, DC, The Brookings Institution. to compare environmental policies which are increasingly stringent over the years, compared to policies that “see saw” – from more stringent to more lax – according to changes in government administrations and political environments. 

\[166\] As described in Chapter 4, once a TCM is included in a state implementation plan (SIP) for air quality, “reasonable progress” toward implementing those TCMs must be rigorously documented. Even substitution of one TCM for another TCM with equivalent air quality benefits has been difficult for many regions. Failure to implement TCMs according to the schedule in the SIP can lead to the entire SIP document being questioned by EPA, and even result in a sanction, a more severe form of a conformity lapse.
5.5.3 ITS Deployment

ITS has been an increasingly important part of the transportation strategy for the Los Angeles region, with operational planning as a key component of the last three Regional Transportation Plans (RTPs) (for the years 1998, 2001, and 2004) (SCAG interview, 2005). For example, in the 2004 RTP, the list of potential solutions to Southern California’s transportation challenges is headed by System Management (“Getting the Most Out of the System”) followed second by Transportation Demand Management strategies. For ITS capital improvement, the RTP projects an investment of $859 million between 2005 and 2030, with $677 million of that going toward Los Angeles County, with the remainder distributed among Orange, Riverside, Ventura and San Bernardino counties. ITS deployment has also been relatively evenly spread across systems for traffic, transit, and information.

5.5.3.1 Traffic

Caltrans has been involved with ITS technologies since the early 1970s, when they first began to deploy their ramp metering network, and with their 42-mile loop system controlled from Caltrans’ downtown Los Angeles office (Caltrans interview, 2005). Since, then Caltrans has continued to expand its ITS operations including variable message signs, CCTV surveillance of traffic conditions, ramp metering, fiber optics interconnection, among other elements. The regional real-time traffic detection system now covers 750 centerline miles, or about half of the urbanized centerline miles in the region (SCAG interview, 2005). According to SCAG, the majority of the ITS for traffic management is centered in the already built-out urban areas, although many newly urbanizing areas, such as the in the Inland Empire, are laying down the infrastructure for ITS applications in preparation for the future. Los Angeles began with ITS when they “realized they could no longer build out” with physical capacity (SCAG interview, 2005). But even newly developing areas are incorporating ITS applications from project inception. According to an ITS program director at Caltrans, “invariably, every large project will include ITS elements – without exception” (Caltrans interview, 2005).

Caltrans has recently relocated its TMC into a 88,000-square-foot building in Glendale, north of the City of Los Angeles downtown. They add that one factor in their successful management of non-recurrent traffic is the co-location of the California Highway Patrol (CHP) in the TMC. CHP has access to Caltrans cameras, while Caltrans has access to CHP’s computer-assisted dispatch system for responding to incidents, which gives both agencies “very fast information on what happens on the highway” and enables a more coordinated response (Caltrans interview, 2005). Currently, the Transportation Management Center is just that, for traffic management. However, through its partnership with Metro and others on the RIITS program, which we will discuss below, ITS program managers are envisioning the TMC as “an information center in the future, [which will] collect and disseminate a lot of information to the general public” (Caltrans District 7 interview, 2005).

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167 Imperial County, the least populated of the counties included in SCAG, would receive no monies for ITS according to the RTP.
For arterial traffic control, the leader in the region is the Los Angeles City Department of Transportation (LA DOT). First developed in preparation for hosting the Olympic Games of 1984, the Advanced Traffic Surveillance and Control (ATSAC) System, is the system of interconnected signalized intersections for optimized network control. Currently, 2,895 of 4,244 of all intersections in the City of Los Angeles are included within the system. Information on traffic conditions come from both electronic loop detectors as well as closed-circuit television (CCTV). However, the most important advancement was the Adaptive Traffic Control System (ATCS), developed by in-house engineers with LADOT. This adaptive traffic signal control system automatically changes cycle length, phase split and offset – based upon real-time traffic conditions, as sense by the loop detectors – simultaneously for all traffic signals under full (Level III) adaptive control. LADOT has also been able to enhance the system to provide signal priority to transit vehicles. According to engineers working on the system, the earlier ATSAC system provided delay reduction of 10-12%, while the addition of adaptive control (ATCS), was between 5-6%, compared to the earlier system of interconnected and centralized, but not fully adaptive control (LADOT interview, 2005). Among the awards that LADOT has received for their innovation in arterial management include the Ford Foundation Award for Local Innovation in State and Local Governments (1992) and the National Energy Award for Energy Efficiency and Renewable Energy from the U.S. Department of Energy (1995). Many cities in the Los Angeles region, particularly in Los Angeles County, are following LADOT’s lead in traffic management systems.

5.5.3.2 Transit

Within the SCAG region, there are over 40 transit agencies (Southern California Association of Governments 2004, p 58). Therefore, we will focus only on some of the larger service providers, and their ITS deployments. One of the largest agencies, Metro or MTA (Los Angeles County Metropolitan Transportation Agency), has deployed a comprehensive set of advanced public transit system technologies that include: transit radio system, Computer Assisted Dispatch (CAD), automatic vehicle location (AVL) which is based on GPS, and automatic passenger counting. A second phase of implementation will include video surveillance system and automatic voice announcement, with both audio and visual (electronic message sign) “next stop” announcements. Another service provider, LADOT, is developing a rapid bus system, providing bus priority on many of the surface streets (Caltrans interview, 2005, p 56).

Given the large number of transit providers, there are also efforts toward providing common fare payment methods for multiple service providers, including initiatives such as the GO-VENTURA smart card and the universal fare card in Los Angeles (Southern California Association of Governments 2004, p 58). The universal fare card has received substantial CMAQ funding in the current regional transportation improvement program (RTIP) for large and small transit

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169 The latter was awarded specifically for the City’s Santa Monica Freeway Smart Corridor Demonstration Project.
providers, including LADOT, Metro, Santa Monica, and a number of smaller transit providers in Los Angeles County.

5.5.3.3 Information and Other

Many of the largest agencies in the Los Angeles area are involved in an initiative to integrate real time information on their systems operations. The project, called Regional Integration of Intelligent Transportation Systems (RIITS) is headed by Metro, and will allow operators to share information on both traffic and transit systems across the region. Currently, Caltrans, California Highway Patrol, LADOT, and Metro are partners in the project, although the vision is to eventually expand the system to include other transit, traffic, airport, public works and emergency response agencies. In the near term, the primary purpose of RIITS is to integrate information on a common framework and enable real-time information sharing. The next (and more difficult) steps, building upon this framework, are to actively coordinate operations between agencies and across jurisdictions, and to provide this integrated and multimodal information to the public. Currently, there are also 12 private information service providers, which can deliver real-time traffic information through the web, email, and PDA devices (SCAG interview, 2005).

Advanced traveler information system, including pre-trip and en-route information on traffic, bus and train, and alternative routing, are also viewed as a complement to transportation demand management (TDM) strategies (Southern California Association of Governments 2004). This will be discussed in more depth in the following section.

5.5.4 ITS-Air Quality Links

5.5.4.1 Projects

In spite of the extensive and advanced ITS systems that have been developed in the Los Angeles region, only a fraction of these have actually been “counted” as measures for reducing transportation-related emissions. Many transportation professionals in the region, from LADOT, SCAG, Caltrans and others, have pointed to the important air quality benefits that ITS has provided (LADOT, SCAG and Caltrans interviews, 2005). For example, one of the most widely referenced ITS application is the Automated Traffic Surveillance and Control (ATSAC) system, considered to have greatly reduced delay, fuel consumption and emissions through LADOT’s successive improvements to the system over the years (eventually leading to the adaptive traffic control system, ATCS). ITS technologies have also played an important role in improving transit – one of the core strategies for improving air quality in the region. Yet, when looking for ITS as a part of a package of transportation control measures in an air quality plan, or as a project funded through the CMAQ program, few of Los Angeles’ ITS current or planned deployments are incorporated. According to SCAG, they would like to not only “claim more credit” but also

\[\text{171 Specifically, the agencies expected to become involved in the future include: Los Angeles International Airport (LAX), the Ports of Long Beach and Los Angeles, Access Services, Long Beach Transit, Santa Monica Big Blue Bus, LA County Department of Public Works, LA County Fire and LA County Sheriff. Metro (2004). }\]

“push more research” regarding the air quality benefits of ITS (SCAG interview, 2005). In contrast to Houston, which was enthusiastically using CMAQ funding and taking credit for the air quality benefits for many of the city’s ITS deployments, Los Angeles seems hesitant to follow this same approach. This is a further paradox when one considers that both congestion and air quality are worse in Los Angeles than any other metropolitan area in the US.

As another example of this seeming “failure” to implement what seem to be “win-win” outcomes, from the technical standpoint, we look to a project that was not implemented. In the mid-1990s, LADOT developed a proposal to use their ATSAC infrastructure as a base to install air quality monitors that could retrieve real-time emissions information for carbon monoxide, and graph that information in using Geographic Information Systems (GIS) to correlate it with traffic. The project would have used CO “hot spots” to identify problems with signal control strategies and make signal timing adjustments based upon levels of CO.Indeed, several monitoring devices were actually installed. According to LA DOT, they had already acquired four monitors, two for downtown and two on the west side of the city in traffic signal control cabinets. According to engineers at LA DOT, they made a proposal to the Air Quality Management District (AQMD) requesting funding to implement the system, however, AQMD, “for some reason, didn’t find interest in it,” and the data was never displayed in any graphical format for use in traffic signal timing improvements (LA DOT interview, 2005). The development engineers were “surprised” that the project was not funded, given what they saw as a clear win-win situation for congestion and air quality, although were not aware of the specific reasons for which the proposal was rejected (LADOT interview, 2005). Although this project did not move forward, it would have represented a highly novel use of information on CO concentrations to manage both traffic and air quality in real time.

Therefore, in Los Angeles, the use of ITS as an emission reduction measure is limited. In particular, arguments regarding the emission reductions from ITS-based traffic flow improvements have not advanced far. However, ITS has gained some currency as a supporting component for transit, and for enhancing many traditional Transportation Demand Management (TCMs) strategies such as ridesharing and carpooling. The Transportation Control Measures (TCMs) for the SCAG region have been grouped into three main categories: (1) high-occupancy vehicles (HOV), (2) transit and system management, and (3) information-based transportation strategies (IbTS). The vast majority of TCMs are for transit, which includes a range of measures for rail, bus, shuttles and paratransit, and intermodal facilities. All bicycle and pedestrian projects (whether connected to transit or not) are also included within the category. This heavy focus on transit and HOV within the set of TCMs reflects the general direction of transportation planning in the Los Angeles region toward transit and trip reduction measures, as discussed earlier.

172 Similar technologies are discussed in Chapter 2, in the section on Energy and Emissions ITS.
Table 5-10 TCM categories and measures for the SCAG region

<table>
<thead>
<tr>
<th>TCM Category</th>
<th>Measures</th>
<th>Number of projects with ITS</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>HOV/HOT measures</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>New HOV lanes, extensions or additions to existing facilities</td>
<td>0</td>
<td>17</td>
<td></td>
</tr>
<tr>
<td>New HOV lanes, with new facility or facility improvement projects</td>
<td>0</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>HOV Bypasses, connectors, new interchanges with ramp meters</td>
<td>1</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>HOT and pricing alternatives</td>
<td>4</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td><strong>Transit Measures</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transit</td>
<td></td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>New rail track or capacity expansion of existing lines</td>
<td>0</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>New rolling stock</td>
<td>3</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Express busways, bus rapid transit (BRT) and dedicated bus lanes</td>
<td>2</td>
<td>45</td>
<td></td>
</tr>
<tr>
<td>Fleet expansion for buses</td>
<td>4</td>
<td>24</td>
<td></td>
</tr>
<tr>
<td>Fleet expansion for shuttles and paratransit</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Intermodal Transfer Facilities</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>New or expanded rail stations</td>
<td>2</td>
<td>19</td>
<td></td>
</tr>
<tr>
<td>New or expanded park and ride lots</td>
<td>0</td>
<td>33</td>
<td></td>
</tr>
<tr>
<td>New or expanded bus stations and transfer facilities</td>
<td>2</td>
<td>19</td>
<td></td>
</tr>
<tr>
<td><strong>Non-motorized Transportation Mode Facilities</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>New or expanded bike and/or pedestrian facilities</td>
<td>4</td>
<td>56</td>
<td></td>
</tr>
<tr>
<td><strong>Information-based Transportation Strategies (IbTS)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Marketing and promotion of rideshare and intermodal service</td>
<td>1</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>ITS/Control System Computerization</td>
<td>2</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Real-time rail, transit, or freeway information systems(^{173})</td>
<td>9</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td></td>
<td>34</td>
<td>268</td>
</tr>
</tbody>
</table>

Source: (South Coast Air Quality Management District 2003, Appendix IVC)

The creation of the category of Information-based Transportation Strategies is an interesting addition to the usual suite of TCMs. It reflects the use of information to both manage the system and provide accessible and convenient alternatives to the use of the single occupancy vehicle. As described by SCAQMD:

“Improving the information content of the transportation system, without the construction of additional capital facilities and hard infrastructure, has been shown to affect the travel behavior and mode choices of consumers in ways that benefits the overall regional transportation system. These improvements reduce congestion and mitigate air pollution, as well as other adverse environmental impacts of transportation activity.” (South Coast Air Quality Management District 2003, Appendix IVC p 19).

This is also a more multi-modal approach to considering both TCMs and ITS, since it considers areas of overlap such as real-time multi-modal information to commuters that may show congestion conditions on the freeway and help commuters plan a transit or bicycle trip or connect with a rideshare for use of the HOV lanes. For example, this is the purpose of the Travel Advisory News Network (TANN), a project managed by the Partnership, and SCAG’s TranStar automated transit trip planning system available via internet or kiosk (South Coast Air Quality Management District 2003, Appendix IVC p 22). The CommuteSmart.info program managed through a five-county partnership – Los Angeles, Orange, Riverside, San Bernardino and

\(^{173}\) There are some inconsistencies in how the actual measures are described within the document. We have included all measures as defined and listed on pages 31-49 in Appendix IVC of the 2003 Air Quality Management Plan.
Ventura – is an exemplary in this respect. Its website guides users (either through its own content, or links to other sites) with comprehensive and real-time information for traffic, carpooling and vanpooling information and ridematching services, list of available vanpools, location of park and ride lots, roadwork advisories, transit trip planners, and even bicycling trip planning.174

Regarding the general ITS content of the TCMs measures list above in Table 5-10, clearly ITS is most prominent in the category of IbTS, and in particular, traveler information systems. ITS also acts as a supporting measure for many transit applications, in particular, for bus rapid transit or shuttles or paratransit. This is not surprising given that the operational success of these systems depend upon technologies such as automatic vehicle location, computer-assisted dispatch, signal priority (for BRT), and advanced voice and data communication links. Indeed, the numbers above are probably very conservative estimates of the number of projects of this type incorporating ITS elements, since only those project descriptions which explicitly identified an ITS component were included.175 Ramp metering and electronic toll collection for HOT lanes are possible ITS applications in support of HOV lanes, and intermodal transfer stations may include information kiosks for transit users. For ridesharing, online ridematching and databases with advanced algorithms for matching riders based upon location and destination are again supporting ITS applications. Within the category of ITS/Control System Computerization, there are only two projects – one for a traffic management system along the Pacific Coast Highway, including bus speed improvements (through signal priority), and another for a automated traffic management system in Corona. However, the presence of only two ITS-based traffic flow improvement measures, out of 268 TCMs in total, indicates that ITS technologies for congestion management and traffic flow improvements are not widely seen as a legitimate emission reductions measures. This is an interesting contrast to the case of Houston, and presents a fundamentally different approach to their region’s TCM strategies.

5.5.4.2 Funding

The Los Angeles six-country region receives nearly 60 percent of all California’s CMAQ funds. Indeed, the Los Angeles region receives more CMAQ funding than any other region in the US, due to its size and the severity of its air quality problems. For example, obligated CMAQ funds for FY 1996-2000 were $584 million (Transportation Research Board 2002, p 266). For the current RTIP, nearly $1.2 billion dollars in CMAQ funds have been designated to specific projects.176

175 The descriptions for each project in the RTIP are relatively brief, and thus do not discuss all aspects of each individual projects. For example, vehicle purchases for advanced vehicles may also include ITS applications, and more than one shared ride program may also support the online ride-matching database service.
176 For comparison to the earlier figure, it should be noted that the CMAQ figures for the 2004 RTIP include CMAQ funds from FY 05/06 to FY 09/10, as well as some carryover CMAQ funding from prior years.
Table 5-11 CMAQ projects from the 2004 RTIP*

<table>
<thead>
<tr>
<th>Projects with ITS</th>
<th>CMAQ Total Cost (000's USD)</th>
<th>Total Cost (000's USD)</th>
<th>CMAQ/ Total Cost Share of Total CMAQ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traffic Flow</td>
<td>33</td>
<td>45,014</td>
<td>136,823</td>
</tr>
<tr>
<td>Traffic Flow-HOV</td>
<td>14</td>
<td>185,897</td>
<td>1,549,788</td>
</tr>
<tr>
<td>Shared Ride</td>
<td>7</td>
<td>7,909</td>
<td>8,387</td>
</tr>
<tr>
<td>Transit</td>
<td>99</td>
<td>852,283</td>
<td>3,387,626</td>
</tr>
<tr>
<td>Transit-Intermodal</td>
<td>12</td>
<td>14,469</td>
<td>18,423</td>
</tr>
<tr>
<td>Bicycle/Pedestrian</td>
<td>31</td>
<td>22,277</td>
<td>38,642</td>
</tr>
<tr>
<td>Demand Management</td>
<td>2</td>
<td>1,081</td>
<td>1,302</td>
</tr>
<tr>
<td>Other</td>
<td>16</td>
<td>25,230</td>
<td>68,709</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>214</strong></td>
<td><strong>1,154,160</strong></td>
<td><strong>5,209,700</strong></td>
</tr>
</tbody>
</table>

Source: (Southern California Association of Governments 2004)

*Includes FY 2004/5-2009-10, and some carry over funding from prior years.

Compared to the list of Los Angeles’ TCMs reviewed above (Table 5-10), there are more traffic flow improvement projects, the majority of which incorporate ITS (25 of 33). These ITS elements include signal coordination, synchronization, and interconnection projects and incorporation into LADOT’s adaptive traffic signal control system. However, transit continues to top the list in number of projects, with 101 in total (including intermodal), and three-quarters of the total CMAQ funding to the region. HOV lanes follow in terms of the share of CMAQ funds used, although with only 14 projects – reflecting the relatively high cost of HOV lane and connector construction. For transit projects, a much higher number of ITS applications were identified compared to the list of TCMs. In fact, 22 of 99 transit projects incorporated some ITS element. The majority of this was to incorporate technology for universal fare system, specifically in Los Angeles County, where there is an effort to develop a common fare payment system across a large number of transit service providers.

Additional ITS applications for CMAQ-funded transit projects, were automated vehicle location (AVL) systems and advanced communications equipment. CMAQ funds, therefore appear to be an important source of funding for many of the advanced public transit systems, in particular, the universal fare system. As seen in Table 5-11, CMAQ funds are only one-quarter of total project cost for transit projects (not including intermodal), meaning that these project are well supported by a range of other funding categories (sometimes up to five or six total funding sources from local, state and federal sources). However, when looking only at those CMAQ-funded transit projects which are ITS (universal fare system, AVL, etc.), the share of CMAQ funding rises to nearly three-quarters of total project cost. This suggests that the ITS applications for transit use CMAQ as an important funding source, and that regional initiatives like the universal fare system might not reach significant levels of deployment if not for the availability of CMAQ funding.

In terms of where projects are being funded, the majority of funds (80%) are spent in Los Angeles and Orange counties, followed by Riverside, San Bernardino and Ventura.
Table 5-12 CMAQ funding by county, FY 2004/5-2009/10 (millions of USD)

<table>
<thead>
<tr>
<th>County</th>
<th>CMAQ funds</th>
<th>Share of 5-county total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Los Angeles</td>
<td>684</td>
<td>59%</td>
</tr>
<tr>
<td>Orange</td>
<td>244</td>
<td>21%</td>
</tr>
<tr>
<td>Riverside</td>
<td>98</td>
<td>9%</td>
</tr>
<tr>
<td>San Bernardino</td>
<td>82</td>
<td>7%</td>
</tr>
<tr>
<td>Ventura</td>
<td>46</td>
<td>4%</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>1,154</strong></td>
<td><strong>100%</strong></td>
</tr>
</tbody>
</table>

Source: (Southern California Association of Governments 2004)

General funding patterns, by type of measure and location, seem to be relatively constant from different time periods when comparing Table 5-11 to the five-county total in Table 5-13. Transit is the largest category for both time periods, although with increasingly shares of CMAQ funding in the most recent RTIP.

Table 5-13 CMAQ program obligations by county, FY 1996-2000

<table>
<thead>
<tr>
<th>County</th>
<th>Traffic flow improvement</th>
<th>Shared ride</th>
<th>Transit</th>
<th>Bike/pedestrian</th>
<th>Demand management</th>
<th>Other</th>
<th>Subtotal</th>
</tr>
</thead>
<tbody>
<tr>
<td>FIVE COUNTY TOTAL</td>
<td>Total Cost (M USD)</td>
<td>CMAQ Cost (M USD)</td>
<td>% of all CMAQ</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Traffic flow improvement</td>
<td>180.6</td>
<td>139.2</td>
<td>23.9%</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Shared ride</td>
<td>17.6</td>
<td>11.4</td>
<td>2.0%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transit</td>
<td>455</td>
<td>368.8</td>
<td>63.3%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bike/pedestrian</td>
<td>8.5</td>
<td>7.5</td>
<td>1.3%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Demand management</td>
<td>2.3</td>
<td>2.1</td>
<td>0.4%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td>79.2</td>
<td>54</td>
<td>9.3%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>743.2</strong></td>
<td><strong>583.0</strong></td>
<td><strong>100.0%</strong></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Los Angeles County</th>
<th>Traffic flow improvement</th>
<th>Shared ride</th>
<th>Transit</th>
<th>Bike/pedestrian</th>
<th>Demand management</th>
<th>Other</th>
<th>Subtotal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traffic flow improvement</td>
<td>67.8</td>
<td>57.1</td>
<td>14.6%</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Shared ride</td>
<td>10.7</td>
<td>5.1</td>
<td>1.3%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transit</td>
<td>385.0</td>
<td>307.7</td>
<td>78.7%</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Bike/pedestrian</td>
<td>0.8</td>
<td>0.7</td>
<td>0.2%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Demand management</td>
<td>0.3</td>
<td>0.3</td>
<td>0.1%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td>22.7</td>
<td>20.3</td>
<td>5.2%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Subtotal</strong></td>
<td><strong>487.3</strong></td>
<td><strong>391.2</strong></td>
<td><strong>100.0%</strong></td>
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<table>
<thead>
<tr>
<th>Riverside County</th>
<th>Traffic flow improvement</th>
<th>Shared ride</th>
<th>Transit</th>
<th>Bike/pedestrian</th>
<th>Demand management</th>
<th>Other</th>
<th>Subtotal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traffic flow improvement</td>
<td>50.8</td>
<td>41.3</td>
<td>54.0%</td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>Shared ride</td>
<td>1.6</td>
<td>1.4</td>
<td>1.8%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transit</td>
<td>21.3</td>
<td>18.9</td>
<td>24.7%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bike/pedestrian</td>
<td>3.8</td>
<td>3.4</td>
<td>4.4%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Demand management</td>
<td>0.1</td>
<td>0.0</td>
<td>0.1%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td>21.9</td>
<td>11.4</td>
<td>14.9%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Subtotal</strong></td>
<td><strong>99.5</strong></td>
<td><strong>76.4</strong></td>
<td><strong>100.0%</strong></td>
<td></td>
<td></td>
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<table>
<thead>
<tr>
<th>San Bernardino</th>
<th>Traffic flow improvement</th>
<th>Shared ride</th>
<th>Transit</th>
<th>Bike/pedestrian</th>
<th>Demand management</th>
<th>Other</th>
<th>Subtotal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traffic flow improvement</td>
<td>61.1</td>
<td>40.0</td>
<td>73.3%</td>
<td></td>
<td></td>
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<tr>
<td>Shared ride</td>
<td>3.4</td>
<td>3.0</td>
<td>5.5%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transit</td>
<td>7.8</td>
<td>6.1</td>
<td>11.1%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bike/pedestrian</td>
<td>0.2</td>
<td>0.1</td>
<td>0.2%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Demand management</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td>6.3</td>
<td>5.4</td>
<td>9.9%</td>
<td></td>
<td></td>
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<tr>
<td><strong>Subtotal</strong></td>
<td><strong>78.7</strong></td>
<td><strong>54.6</strong></td>
<td><strong>100.0%</strong></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Orange County</th>
<th>Traffic flow improvement</th>
<th>Shared ride</th>
<th>Transit</th>
<th>Bike/pedestrian</th>
<th>Demand management</th>
<th>Other</th>
<th>Subtotal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traffic flow improvement</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shared ride</td>
<td>0.9</td>
<td>0.9</td>
<td>2.8%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transit</td>
<td>17.6</td>
<td>15.6</td>
<td>47.8%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bike/pedestrian</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Demand management</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td>27.5</td>
<td>16.2</td>
<td>49.5%</td>
<td></td>
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</tr>
<tr>
<td><strong>Subtotal</strong></td>
<td><strong>46.0</strong></td>
<td><strong>32.6</strong></td>
<td><strong>100.0%</strong></td>
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</table>

<table>
<thead>
<tr>
<th>Ventura County</th>
<th>Traffic flow improvement</th>
<th>Shared ride</th>
<th>Transit</th>
<th>Bike/pedestrian</th>
<th>Demand management</th>
<th>Other</th>
<th>Subtotal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traffic flow improvement</td>
<td>1.0</td>
<td>0.8</td>
<td>3.0%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shared ride</td>
<td>1.0</td>
<td>0.9</td>
<td>3.2%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transit</td>
<td>23.3</td>
<td>20.7</td>
<td>73.4%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bike/pedestrian</td>
<td>3.8</td>
<td>3.4</td>
<td>11.9%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Demand management</td>
<td>1.9</td>
<td>1.7</td>
<td>6.0%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td>0.8</td>
<td>0.7</td>
<td>2.5%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Subtotal</strong></td>
<td><strong>31.8</strong></td>
<td><strong>28.2</strong></td>
<td><strong>100.0%</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: (Transportation Research Board 2002, p 267)

These CMAQ spending patterns tend to support the observations in the report by the Transportation Research Board on the CMAQ program. Compared to Houston, which saw congestion mitigation and air quality goals as roughly the same importance for CMAQ funding, the majority of planners, managers and analysts in Los Angeles interviewed for the report saw air quality improvements as the primary goal (Transportation Research Board 2002, p 264). Many
also saw congestion mitigation as another important goal, and no fundamental conflict between the two. SCAQMD, however, did not see these two goals as necessarily compatible (ibid, p 264), reflecting a skepticism regarding the air quality benefits from operational improvements.

In addition to looking what is being funded (traffic flow improvements, transit, rideshare), and where, we should also look closely at who is being funded. Going through the regional transportation program in detail, one sees that the Los Angeles County MTA (Metro) dominates the CMAQ spending profile. For fiscal years 2004/5 to 2009/10, Metro received the bulk of the CMAQ funding pot – receiving 46% of all CMAQ funds during that time period. Not surprisingly, nearly all of that funding went toward transit improvements, ranging from operating assistance, purchase of lower emission vehicles and light rail cars, and a few ITS components, such as ITS outfitting of BRT stations, and universal fare payment systems. Therefore, while some counties, such as San Bernardino and Riverside, more aggressively pursue traffic flow improvements using CMAQ funds, they represent only a small portion of allocated CMAQ funding in the region (7% and 9%, respectively). Spending in Los Angeles County, and specifically, the spending decisions of Metro, dominate the breakout of CMAQ funds for the region.

5.5.4.3 Evaluation

Unlike other regions, SCAG incorporates Transportation Control Measures, ITS, and other operational projects in their Regional Transportation Plan into their general transportation modeling approach that is used for determining conformity. They suggest two reasons why modeling aggregate emissions reductions from all TCMs taken together is a better approach than off-model (or “back-of-the-envelop”) analysis for each individual measure. First, the tools use from transportation emissions modeling at the network level are “a more exact science” than the “off-model” methods typically used to measure emissions changes from individual TCMs. Second, they suggest that adding up emissions reductions from individual TCMs would present a problem of double counting, as there are overlapping effects between various strategies. Therefore, they suggest that “it is important that estimates of the actual emissions reductions indicated by the 2001 RTP and TCMs should be quantified only at the systems-level. For the 2003 Air Quality Management Plan, the reductions from all TCMs were as follows.

Table 5-14 TCM and total RTP emission reductions (tons per day) in 2010

<table>
<thead>
<tr>
<th></th>
<th>Transportation Control Measures (TCMs)</th>
<th>Total reductions for the RTP (including TCMs)</th>
<th>TCM reductions as a percentage of total RTP reductions</th>
</tr>
</thead>
<tbody>
<tr>
<td>VOC</td>
<td>5.6</td>
<td>15.7</td>
<td>36%</td>
</tr>
<tr>
<td>NOx</td>
<td>1.0</td>
<td>7.8</td>
<td>13%</td>
</tr>
<tr>
<td>CO</td>
<td>60.8</td>
<td>161.8</td>
<td>38%</td>
</tr>
</tbody>
</table>

Source: (South Coast Air Quality Management District 2003, p 8)

177 One example of overlapping effects would be changes in ridesharing (and thus VMT) from the construction of HOV lanes and rideshare marketing strategies.
Although the final calculations for TCM emissions reductions are done using the regional transportation and emission model, in the process of negotiating which measures to incorporate into the final transportation plan, the Sub-regional Air Quality Planning, Analysis and Modeling Group (SAQ-PAM), “oversaw an extensive off-model analysis effort to capture the air quality benefits of local projects such as grade separation and traffic signalization” (South Coast Air Quality Management District 2003, p 68). This highlights that although a more “robust” and detailed model is used for claiming credit for these measures in the regional transportation plan, in the actual dialogue between the local government, sub-regional government, and regional entity (SCAG), more back-of-the-envelop calculations are necessary to compare and prioritize measures.

For CMAQ-funded projects, however, there is a separate evaluation methodology, which has been developed by CARB, in cooperation with Caltrans and California Air Pollution Control Officers Association (CAPCOA), and is updated regularly by CARB. This evaluation methodology – “Methods to Find the Cost-Effectiveness of Funding Air Quality Projects” – is intended for the evaluation of comparison of the cost-effectiveness of both CMAQ and Motor Vehicle Registration Fee projects (California Air Resources Board 2005). However, the methodology is not used by all agencies. The process for CMAQ project development and selection is decentralized, with the individual counties responsible for selecting and reporting to Caltrans on CMAQ projects. Some agencies, such as Metro, choose to use their own transportation and emissions models to assess the emissions and travel impacts of their proposed CMAQ projects (Transportation Research Board 2002, p 263).

Compared to Houston, the Los Angeles methodology covers fewer individual measures (10 in Los Angeles compared to 48 in the MoSERS handbook). With respect to ITS, the only ITS-related measure included in the methodology is signal coordination and optimization. While the calculations used by the two manuals are essentially the same – using emission factor changes from changes in average speeds on the affected arterial – there is an important difference. In the CARB manual, a more conservative approach to estimating the emission reductions from CMAQ project is used. Although there is no explicit manner for incorporating induced demand, the methodology does introduce a rough correction factor (diving initial emission benefits by one half) to account for the growth in travel that will likely take place on the improved corridor.

\[
\text{Annual Emission Reductions} = (0.5) \times (VMT) \times ((\text{before emission factor})-(\text{after emission factor}))
\]

where: \( VMT = (\text{days of use}) \times (\text{congested traffic volume}) \times (\text{length}) \)

---

178 The most recent update is May 2005. The methodology is available in Microsoft Access database, with equations and default values. See www.arb.ca.gov/planning/tsaq/eval/eval.htm.

179 According to the manual, “initial speed improvements decline to zero improvement by the end of the effectiveness period. In order to account for this, the emission reduction equation reduces initial emission reduction benefits by one half.” California Air Resources Board (2005). Methods to Find the Cost-Effectiveness of Funding Air Quality Projects: For Evaluating Motor Vehicle Registration Fee Projects and Congestion Mitigation and Air Quality Improvement (CMAQ) Projects. Sacramento, CA, California Environmental Protection Agency, in Cooperation with the California Department of Transportation: 61 pages.
Yet, it does not indicate to what extent that expected travel growth is induced travel, or exogenous growth in travel demand. The CARB manual also highlights the possible detriments to air quality from increasing speeds substantially.

"Signal timing and other actions that increase traffic speeds and flows to the detriment of overall traffic performance or that offer a significant inducement to travel by auto are not air quality beneficial. Speeds higher than 36 mph begin to increase NOx emissions and may also discourage walking and bicycling. These results may be counterproductive to meeting clean air goals" (California Air Resources Board 2005, p 26).

It is interesting to note that the language regarding the potentially negative effects of traffic flow improvement projects – such as signal synchronization, interconnection, and timing improvements – is much stronger than that used in Houston’s MoSERs handbook. On the other hand, many interviewees others felt that the emissions reductions from projects such as Los Angeles DOT’s ATSAC system are underestimated, noting that most of the emissions reductions come from the reduction of acceleration/deceleration events, which are not incorporated in the equations or emissions factors, which are based on average speeds (SCAG interview, 2005).

In the Los Angeles region, the funding, evaluation, deployment and operations are divided with a high degree of specialization not only between organizations, but within the agencies themselves. In the interview with Caltrans District 7, managers and chiefs of various offices for ITS, corridor environmental studies, and air quality studies, were interviewed together. For example, although many ITS projects are funded through CMAQ program funds, and are incorporated in the regional and state air quality plans as Transportation Control Measures, managers from the ITS office were often not familiar with the air quality topics or terminology from the standpoint of either funding or evaluation. This differs from other cases studies, where project managers responsible for deployment and operations of ITS were often well aware of their use of CMAQ funding (often actively pursuing it), and the presence of ITS measures in the air quality plan. This reflects both the relative size of the organizations in each city, and the number of individual projects that must be coordinated on a regional scale. While other regions may have a few dozen CMAQ projects included in their transportation improvement program, the SCAG region will have hundreds, many of which will be more expensive on an individual project basis as well.

Ironically, when discussing the issue of induced demand from ITS, the ITS program manager was quick to made the link between ITS and induced travel, while the planner from the office for environmental engineering and feasibility studies for corridor-level analysis, had apparently not fully considered the issue before.

ITS Manager: “To address your question, from my office, we never looked at it from an air quality point of view. Our concern is always safety, mobility, congestion. But, you can look at it this way, if you provide a better service to the motorist, and the cars are moving faster, maybe they are emitting more pollutants. And, if you have a more efficient system, just like through signal synchronization, and cars are moving through the system faster, and then more cars are getting onto the system, and then maybe this has an adverse effect.”

Environmental Engineering and Feasibility Study Planner: “Actually, you’re right, when you run the model, the travel demand forecast model, of course, it builds in that latent demand, so as soon as you free up space on a facility by making it flow better, you could
be inducing more trips onto it – so someone who may not have made that trip, or may have taken the bus instead or walked, decide that they’ll jump in their car because now it’s going faster. That’s a good point, I hadn’t thought of that” (Caltrans District 7 interview, 2005).

Therefore, in the Los Angeles region, there is a high level of fragmentation both between organizations – with multiple levels (local, subregional, regional, and state) for both air quality and transportation planning – as well as within organizations.

5.5.5 Summary

Los Angeles has undertaken a highly interesting experiment in the realm of transportation and air quality planning, in what is probably one of the most complex urban areas in the world. The emphasis on transportation demand management and transit that began in the 1980s represents, according to Wachs, a “change of direction in transport policy [that] attempts to reverse a trend which has been powerful for sixty years” (Wachs 1993, p 6). The de-emphasis of freewy construction has apparently given an advantage to ITS. As the options for physical capacity are limited, or physical capacity is simply no longer a desirable option for the high-level transportation policymakers and planners (although, surely with many exceptions), capacity expansion through ITS-based operations is an increasingly attractive alternative.

Figure 5-20 System priorities for the 2004 Regional Transportation Plan (RTP)

![Diagram](source: Adapted from (Southern California Association of Governments 2004, Figure 4.2 p 84))

Indeed, as shown in Figure 5-20, the base of the system management strategy is monitoring and evaluation, then maintenance and preservation and demand management, followed by a range of
operations-oriented approaches that can be supported by ITS. Only the small triangle at the top represents actual physical capacity expansion, and even this includes HOV and "mixed use" or general traffic capacity additions, and transit system expansions. While this is highly schematic and might not necessarily represent actual funding levels, it does represent the philosophy that is guiding many of the transportation strategies, policies, and investments in the L.A. region.

Meanwhile, the range of new transit and TDM measure have opened some opportunities for experimentation with ITS as a supporting technology that increases the operational efficiency and attractiveness of these travel alternatives. ITS is still not easily found on the list of TCMs for the region, although it does appear in many projects for CMAQ funding. This may be in part because the bar is set higher for TCMs by SCAQMD and CARB in terms of their unequivocal air quality benefits. For example, even though the benefits of a new bicycle or pedestrian facility may be small, they are more certain to lead to emissions reductions, compared to a traffic flow improvement projects which could increase speeds too much (and therefore increase NOx), or induce additional travel (and therefore increase all emissions).

ITS has been implemented as projects funded through CMAQ, in particular, for transit and traffic flow improvements. ITS has also supported some CMAQ-funded rideshare activities, HOT lane operations and even bicycle facilities, although on a more limited basis. CMAQ funding for traffic flow improvements has not been as prominent a share of total funding as in Houston, for example. Yet, of the traffic flow improvements that are undertaken, nearly two-thirds are ITS based. In terms of overall CMAQ funding for the five-county area, the vast majority has gone to transit. There seems to be a lack of support by CARB and SCAQMD for ITS-based traffic flow improvements and their air quality impacts. As opposed to other regions, such as Houston, they take the other view on induced demand from ITS, thus taking a more pessimistic view regarding ITS’ potential to improve air quality. This is even built into their assessment procedures for ITS projects such as signal coordination.

Although Los Angeles has extensive and advanced ITS applications, it has not been as aggressive as Houston in counting those ITS deployments toward emission reductions when formulating its air quality plans. Some ITS-based traffic flow improvements are funded through the CMAQ program, requiring quantification of its emissions benefits. However, ITS-based traffic flow improvements are not as frequently included in the TCM project list. Los Angeles has begun to explore different mechanisms for using Information-based Transportation Strategies, an innovative approach to conceptualizing the link between ITS and travel demand management through improved information to travelers. While the number of projects and level of funding dedicated to this area is still relatively low (although the low levels of funding also stem from the low-cost nature of these projects), this may prove to be an increasingly important area for innovation in the future.
5.6  BOSTON, MASSACHUSETTS

5.6.1 Background

5.6.1.1 The City

Of the five case study cities, Boston is the oldest and most built out of the metropolitan areas. The population of the Boston MPO region is just over 3 million, encompassing a region within a radius of approximately 25 miles from the City of Boston, extending out to Interstate 495 (Central Transportation Planning Staff 2003, p 2-1). As generally seen with the older, established cities in the Northeast, population growth has been slow in recent years, with an average annual growth of 0.6% during the 1990s. Nevertheless, there are continued pressures toward suburbanization, with continued conversion of agricultural and forested lands for use by new single-family housing developments as well as commercial and industrial spaces. In addition, while employment has grown within the central area of the MPO, the strongest growth in employment has been on the peripheries of the MPO, outside of Route 128 (Central Transportation Planning Staff 2003, p 2-2).

5.6.1.2 Transportation

Recent transportation policy in Boston can hardly be discussed without reference to the Central Artery/Tunnel project (the “Big Dig”), which has been the core issue in transportation planning and financing in the Boston area during the 1980s, 1990s and into the new century. As emphasized by Altshuler and Luberoff, in their careful analysis of the political forces that continually shaped and reshaped the CA/T project, “it is, by far, more expensive than any other highway project ever undertaken in the United States” (Altshuler and Luberoff 2003, p 120). However, in addition to the massive price tag – $14.6 billion in 2002 – and decreasing share of federal participation in that cost (58% in 2002), future transportation initiatives have also been shaped by the more than 1,500 mitigation agreements that were negotiated in order to move the project forward (Altshuler and Luberoff 2003, pp 109, 116). From the transportation viewpoint, the most significant of those agreements are the transit agreements which, as will be discussed later, are still being debated.

180 These figures from CTPS are lower than those reported above in Table 5-4.
Congestion levels in Boston are fairly high, with Boston ranking 21st for the most congested cities in 2003 (Schrank and Lomax 2005). With the completion of the CA/T project, the shift has been from physical capacity expansion projects to projects that are primarily maintenance and operations in nature. According to the latest long-term Regional Transportation Plan for the Boston region: “Most of the transportation programs and projects that will be funded in the next twenty-two years do not add capacity to the transportation system” (Central Transportation Planning Staff 2003, p 1-1). Translating this into funding allocations, maintenance and improvement of the existing infrastructure will comprise 70% of total revenues (highway and transit), while system expansion will comprise the other 30%. While ITS is identified as an element of “maintenance and improvement” projects, only 2% of the highway funding for

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181 It should be noted that this 2003 ranking is significantly lower than earlier years. In 2001 and 2002, Boston ranked fifth in congestion with a travel time index of 1.45, above cities such as New York, Miami and Houston. This change in ranking may reflect both changes in the methodology, and possibly a real reduction in congestion levels as the Big Dig reached completion.

182 Interestingly, the wording in this quote also suggests that improved operations and ITS are not considered capacity expanding, even though effective capacity is expanded.
maintenance and improvement funding will be allocated to ITS, about the same amount as for bicycle and pedestrian projects. The vast majority of maintenance and improvement funding will be allocated to bridge, interstate and roadway maintenance and rehabilitation (31%, 10% and 35% respectively).

Public transit represents an important mode of travel in the Boston region, particularly for travel to the downtown area. In the entire Boston MPO region, transit accounts for 6.8% of all trips to all destinations, urban and suburban. Looking at only trips to downtown, transit represents 42% of all trips, and 55% of all work trips (Central Transportation Planning Staff 2003, p 2-1). The Massachusetts Bay Transportation Authority (MBTA) provides the majority of transit service, including a mix of modes – rapid transit, trackless trolley, express and local bus service, and commuter rail and boat. Looking only at surface transportation modes, this accounts for 1.2 million trips on the average weekday.

**Table 5-15 MBTA transit services and ridership**

<table>
<thead>
<tr>
<th>Service</th>
<th>Components</th>
<th>Ave. Weekday Ridership (trips)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rapid Transit and Streetcar</td>
<td>Rapid transit lines (Red, Orange, and Blue Lines) Streetcar lines (Green Line, Ashmont-Mattapan) Bus Rapid Transit (Silver Line)</td>
<td>699,000</td>
</tr>
<tr>
<td>Bus and Trackless Trolley</td>
<td>170 bus routes, 4 trackless trolley lines</td>
<td>376,000</td>
</tr>
<tr>
<td>Commuter Rail</td>
<td>13 radial lines (North Side and South Side)</td>
<td>142,000</td>
</tr>
<tr>
<td>Commuter Boat</td>
<td>6 services</td>
<td>1.4 million/year</td>
</tr>
</tbody>
</table>

*Source: (Central Transportation Planning Staff 2003, p 2-9)*

Although overall growth in the Boston region is slow, there are important changes within the region that are straining the existing highway and transit systems. Many of the more mature suburbs, such as Arlington, Dedham, Medford, and Watertown lost population during the 1990s, while the outer suburbs and rural exurbs around the Route 495 corridor, experienced high growth (Central Transportation Planning Staff 2003, p 3-2). Despite these trends, which usually place public transit at a further disadvantage, the long-range Program for Mass Transportation still projects that transit trips in the region will increase, from the current 6.8% to nearly 7.5% by 2025 (Central Transportation Planning Staff 2003, p 2-1).

5.6.1.3 Institutions

The Boston Region MPO represents 101 communities, through a cooperative board of fourteen members from the state and local level, half of which are cities and towns. Planning and analysis is supported by the Central Transportation Planning Staff (CTPS), which, as the name suggests, acts as the staff to the MPO Board. The CTPS also works with the Massachusetts Area Planning Council, which is responsible for the population and employment forecasts that form the basis of the long-range planning efforts as well as the conformity determination.

The Executive Office of Transportation (EOT) is responsible at the state level for overarching transportation policy decisions, while the Massachusetts Highway Department (MassHighway),
is responsible for highway planning, construction and maintenance for the state roadway network. However, there is strong overlap between these institutions in terms of mission and personnel at the top levels. The Massachusetts Turnpike Authority (MassPike) owns and operates the region’s toll facilities, including the Massachusetts Turnpike (Interstate 90) and the Sumner, Callahan, and Ted Williams tunnels, while the Massachusetts Port Authority (Massport) owns the Tobin Memorial Bridge and access roads to Logan Airport. MassHighway and the MassPike are also key players in ITS deployment. The City of Boston, and other cities such as Cambridge, Newton, and others monitor traffic flows on local streets, and coordinate the traffic signals.

As noted above, Massachusetts Bay Transportation Authority (MBTA) is the primary transit service provider for the region, although the MBTA district actually encompasses a large number of communities (175) outside of the Boston MPO region (101 communities). Additionally, the MBTA provide bus service through contract to five private carriers, and subsidizes nine additional carriers through the Inter-District Transportation Program (Central Transportation Planning Staff 2003, p 2-12).

The Massachusetts of Department of Environmental Protection (MADEP) is the lead agency for the development of the State Implementation Plan (SIP) for air quality. It works in conjunction with CTPS in establishing the on-road mobile source emissions budget for the Boston MPO region, as well as identifying the TCM commitments that are included in the SIP.

Among the cases, Boston is unique in that it is the only state capital, meaning that the offices for the Massachusetts Highway Department are all located within the Boston metropolitan area, and interaction between the state agency headquarters and local agencies is more direct, rather than working through state agency district offices. In transportation, this is evident in the actual physical co-location of the offices of the major transportation agencies in the State Transportation Building at Park Plaza in downtown Boston, which brings together the major players in state transportation policy and planning. In addition, the Secretary of Transportation for the Commonwealth of Massachusetts (therefore heading the Executive Office of Transportation), is the chair of the MBTA Board of Directors and has direct oversight for MassHighway. There is also an important federal presence in Boston, both for transportation, through the Federal Highway Administration which houses its Volpe National Transportation Systems Center in Cambridge, and for environmental protection, through the EPA’s Region I offices in downtown Boston.

5.6.2 Air Quality History

Under the 1990 CAAA, the entire Commonwealth of Massachusetts – divided into the Boston non-attainment area (Eastern Massachusetts) and the Springfield non-attainment area (Western

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183 For areas outside of the Boston MPO, MassHighway provides the emissions estimates using a statewide travel demand model.
184 The Eastern Massachusetts ozone non-attainment area includes the following counties: Barnstable, Bristol, Dukes, Essex, Middlesex, Nantucket, Norfolk, Plymouth, Suffolk and Worcester. In addition to the Boston MPO, there are nine other MPO regions, although the Boston MPO is by far the largest. Central Transportation Planning
Massachusetts) – was designated as serious non-attainment of the one-hour ozone standard, with an attainment date of 1999. However, the attainment date was later extended by EPA to 2003, and then to 2007 (McGahan 2005, p 3). Progress has been made in bringing down ozone levels, and since the mid-1990s there have been exceedances only a few days of each year.

Figure 5-22 Number of days above 1-hour ozone standard for the Boston Region

![Graph showing the number of days above the 1-hour ozone standard for the Boston Region from 1987 to 2004.](image)

*Source: (Massachusetts Department of Environmental Protection 2004, Figure 1)*

In addition to ozone, carbon monoxide has also been a criteria pollutant of concern, particularly during the winter months. In 1996, Boston and surrounding communities (Cambridge, Chelsea, Everett, Malden, Medford, Quincy, Revere and Somerville) were re-classified as in attainment for CO. Nevertheless, because these areas are still required to have a CO “maintenance” plan as part of the SIP, they remain under federal scrutiny, albeit more limited, and must continue to perform conformity analysis for the SIP.

5.6.2.1 Sources

Mobile sources comprise half of the total NOx emissions for the 10-county Eastern Massachusetts non-attainment area, with off-road mobile sources contributing an additional 30% to total NOx. VOC emissions, on the other hand, are distributed more evenly across area sources (40%), on-road mobile sources (29%), and off-road mobile sources (27%) (Massachusetts Department of Environmental Protection 2003).


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Local emissions and control strategies are only part of the picture. Massachusetts – along with a number of other New England states – was unable to meet the 1994 deadline for completing its demonstration of ozone attainment by 1999. These states had found that the transport of ozone and ozone precursors from upwind areas "made it impossible for Massachusetts and some other non-attainment areas in the Northeast to plan for and reach attainment by the dates specified in the CAA" (Massachusetts Department of Environmental Protection 2002, p 1). There were two key issues related to the ozone transport issue. First, many of the upwind areas such as New York and New Jersey were classified at higher categories for ozone non-attainment, meaning their attainment deadlines were later, and thus they would not be putting all controls into place by 1999. Second, some upwind contributing states, although they were “exporting” ozone and its precursors, did not themselves have local ozone problems. These areas, therefore, were not planning to implement any control measures. As a result, for the downwind areas such as Boston that were importing ozone and ozone precursors, could not meet the attainment deadline without also addressing these upwind sources – ranging as far as the Ohio River Valley, but also from more nearby, including New York, New Jersey and Philadelphia. In order to address this issue, the 37 “eastern-most” states from the Midwest to the Northeast, plus the District of Columbia, formed the Ozone Transport Assessment Group (OTAG), which studied the phenomenon of ozone transport between 1995 and 1997.\textsuperscript{185} The EPA, drawing upon the OTAG final report and recommendations, issued rules that would require 22 states plus the District of Columbia to submit SIP revisions incorporating controls aimed to reduce not only their local ozone problem, but also their contribution of NOx to downwind non-attainment areas.\textsuperscript{186}

\begin{figure}
\centering
\includegraphics[width=\textwidth]{figure5-23.png}
\caption{1999 Emissions inventory for the Boston Region}
\end{figure}

\textit{Source: (Massachusetts Department of Environmental Protection 2003, Tables 1.5 and 1.6)}

\textsuperscript{186} In October 1998, the EPA published its “Finding of Significant Contribution and Rulemaking for Certain States in the Ozone Transport Assessment Group Region for Purposes of Reducing Regional Transport of Ozone” (62 FR
5.6.2.2 Actions

In the meantime, however, Massachusetts was already pursuing a number of local controls. In particular, Transportation Control Measures (TCM) and transit have formed an important component of air quality strategies in Boston. Even before the 1990 CAAA, the Massachusetts DEP had submitted SIPs to the EPA in 1979 and 1982, which both included TCMs. The majority of the 1979 TCMs were transit improvements and expansions, but they also incorporated ridesharing programs (MassRIDES), parking freezes and resident sticker programs, HOV, bikeway programs, park and ride, and flexible work hours. The 1982 SIP TCMs continued upon the 1979 TCMs, and added further public transit improvements, bicycle facilities, park and ride, and enforcement of parking controls. Taken together, these TCMs were intended to reduce VMT by discouraging the use of single occupancy vehicles for trip making, and provide alternatives with transit and bicycle facilities.

In addition, as part of the Central Artery/Tunnel project, a number of mitigation projects were required to move forward with the project. These mitigation projects were impressive both in the number (more than 1,500), size and cost of the projects. As described by the MassPike:

"The scope of the Mitigation Program reflected the spectacular size of the CA/T project itself. Mitigation cost about one-third of the project's budget. Activities ranged from one-on-one contracts with residents and business people up to temporary viaducts costing dozens of millions of dollars. Keeping the elevated highway open as tunneling proceeded directly underneath cost $600 million in itself, which reflects the engineering complexity of mitigation."

Indeed, in addition to the engineering complexity of the Big Dig, was the institutional complexity of managing the project and mitigation of its impacts. Although there were several types of mitigation agreements, including traffic, community outreach and environmental – the most significant impact on the transportation system has come from the air quality transit mitigation agreements. When the CA/T project’s draft Environmental Impact Statement (EIS) was released in early 1990, it projected improvements in air quality from both the CA/T itself, as well as from several transit projects that were included in the modeling. The Conservation Law Foundation (CLF), a non-governmental organization representing environmental interests and working through a combination of litigation and publicity, challenged the validity of the EIS, arguing that the transit projects that were included in the modeling must be guaranteed; if not, they threatened to legally challenge the project (Altshuler and Luberoff 2003, p 105). Although

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187 Indeed, according to the 2002 SIP for the Eastern Massachusetts Area, they are already “currently implementing all of the reasonable available TCMs listed in the Clean Air Act.” Massachusetts Department of Environmental Protection (2002). 2002 Eastern Massachusetts Supplement to the July 1998 Ozone Attainment Demonstration State Implementation Plan Submittal: Final Submittal, September 6, 2002. Boston, MA, Bureau of Waste Prevention, Division of Planning and Evaluation.

the CLF used the air quality modeling results for the EIS as the grounds for litigation, the “prime concerns were transit and transportation controls rather than any features of the CA/T itself” (Altshuler and Luberoff 2003, p 109).

As a result, much of the responsibility for both the SIP approval and CA/T permitting fell upon the MBTA. As noted in the 2003 Program for Mass Transportation:

“The Commonwealth has pursued transit as a way to answer the requirements associated with the State Implementation Plan (SIP) for the Clean Air Act and the mitigation required by environmental agencies... to allow for the permitting of the Central Artery/Tunnel (CA/T) Project” (Central Transportation Planning Staff 2003, p 2-16).

The CA/T and SIP projects formed an aggressive plan of transit system expansions and improvements – including commuter rail, bus rapid transit, subway and bus service improvements, water shuttles – as well as HOV lanes, and park and ride lots. These commitments, for the most part, involved important physical capital investments in the transit system – such as rail extensions, station improvements, and new vehicle procurements. Of the approximately 30 CA/T SIP commitments as listed in the 2004 Regional Transportation Plan, nearly two-thirds have been implemented or are in progress (Central Transportation Planning Staff 2003, Table I-3). However, there are critical obstacles facing some of the remaining projects, which are highly complex and controversial.

5.6.2.3 Issues

In recent years, three CA/T SIP transit commitments – the Green Line Arborway restoration, the connection between the Blue Line and Red Line, and the Green Line extension to Medford – have increasingly come into the public eye, bringing planners head to head with the original agreements that were necessary to move forward with the CA/T project. Changing or modifying these original agreements would prove to be non-trivial. Indeed, even new institutional processes had been built up around the tracking and implementation of the CA/T mitigation commitments, including a computerized tracking system and reporting structure, and what is referred to as planners as the “Red Book” or the “Annual Report on the Transit Commitments” (CTPS interview, 2005).189

Altshuler and Luberoff, writing in 2002, noted that even though “in its final form this agreement left room for the substitution of listed projects with others of comparable air quality value ... no administration has seen fit to risk [CLF’s] wrath by proposing substitutions” (Altshuler and Luberoff 2003, p 233). While these commitments remained relatively untouched during previous administrations, the administration of Governor Mitt Romney has appeared to be more willing to challenge these agreements. The shift during the Romney administration has been emphasize the use of “objective criteria” in evaluating transportation projects and plans and programming funds – thereby adopting a “more rational, transparent approach to project

189 This is in addition to the quarterly reports that the Executive Office of Transportation has been required to send to the Conservation Law Foundation since March 1992; as well as the “Quarterly Report on the Re-evaluation of the Three Outstanding SIP Commitments” prepared for FHWA and FTA since early 2005.
prioritization” (McGahan 2005). In re-examining these three outstanding SIP transit commitments – the Green Line Arborway restoration, the Blue Line/Red Line connector, and the Green Line Extension to Medford – as part of the Program for Mass Transportation, the performance, according to the state’s objective criteria, was not competitive with other preferred alternatives. Yet, these three projects were legal commitments included both for the CA/T permitting, the SIP, as well as the Administrative Consent Order signed in 2000 and updated in 2005, which clarified and expanded upon both the CA/T and SIP commitments. As a condition to substituting the three outstanding transit projects, the Department of Environmental Protection set the bar higher, requesting that replacement projects provide 110% of the original reductions. As can be seen in Table 5-16, the proposed projects reductions well exceed the original air quality benefits.

| Table 5-16 Original transit agreement projects and proposed substitutions |
| --- | --- | --- | --- |
| **Original Transit Agreements** | **VMT** (miles/day) | **HC** (kg/day) | **CO** (kg/day) | **NOx** (kg/day) |
| Arborway Green Line Extension | 4,781 | 7 | 108 | 2 |
| Blue Line/Red Line Connector | 21,520 | 17 | 190 | 34 |
| Green Line Extension to Medford Hillside | 27,730 | 22 | 244 | 44 |
| **Total** | 54,031 | 45 | 543 | 80 |
| **Proposed Transit Substitution Projects** | | | | |
| Fairmont Commuter Rail Improvement | 1,100 | 1 | 15 | 2 |
| 1,000 Parking Spaces | 11,900 | 16 | 166 | 21 |
| Enhanced Green Line Beyond Lechmere** | 80,300 | 83 | 1,016 | 114 |
| **Total** | 93,300 | 100 | 1,197 | 137 |

*Numbers rounded from original. **Reconfigured Green Line Extension to Medford Hillside
Source: (Massachusetts Executive Office of Transportation 2005)

For many supporters of the original projects, how the project ranks when applying objective criteria is beside the point. For example, Fred Salvucci, the former Secretary of Transportation who was the central player in the negotiation of the commitments needed to secure approval of the CA/T, commented on the idea of replacing the SIP transit agreements that he had forged with the CLF several years earlier. In a June 22, 2005 MPO-sponsored public meeting on the SIP transit commitments, Salvucci raised the following issues:

"[W]e signed [the] commitment with the intention of completing the projects by 2000. It is unfair to compare committed project to new projects. Air quality was not the primary basis for choosing the committed projects. If the committed projects did not go forward, the Commonwealth was required to replace those projects with projects with the same or more air quality benefits in the same neighborhood. The original deal should be honored" (italics added).

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190 These “objective criteria” include: utilization, mobility, cost-effectiveness, air quality, service quality, economic and land use impacts, and environmental justice.
Although these commitments were originally made with CLF using the argument of the air quality projections, the air quality benefits are evidently not the only motivating factor for the agreements, as noted in the comments by Salvucci. It also suggests a type of "culture clash" between on the one hand, the idea of fairness and negotiated outcomes including affected and interested groups, and on the other hand, an outcome based on the ranking of projects according to so-called objective criteria.\textsuperscript{192} The outcome will probably be a mixture of the two, using "objective" criteria to redesign projects and propose alternatives, but keeping in mind the original commitments and the pressure of the groups (primarily neighborhoods) that stood to gain from those commitments. Douglas Foy, president of CLF at the time that the original transit agreements were negotiated, now serves as the Secretary of Commonwealth Development. Ironically, in contrast to Salvucci, with whom he negotiated the original agreements, Foy taken the other stance, advocating substituting the original transit agreements.\textsuperscript{193}

* * *

We have focused here on the SIP transit agreements for the Big Dig and the fights over how, when and even if they will be completed, in large part because they will prove to have an important impact on how ITS is used for air quality. However, strictly from the viewpoint of improving Boston's air quality, these transit agreements actually play an almost insignificant role in improving actual air quality. In fact, the air quality improvement strategy for the Eastern Massachusetts Area essentially consists of regulations related to cleaner fuels and vehicles, for example, adopting California's LEV standard, and waiting for upwind areas such as New York, New Jersey and Connecticut to reduce their NOx emissions (through the so-called NOx SIP called, discussed earlier).\textsuperscript{194} Beyond the transportation control measures that were already in place, such as the transit agreements, parking freezes in Boston and Cambridge, park and ride lots and HOV lanes, additional transportation control measures were not considered for the 2002 SIP for the Eastern Massachusetts Area.

5.6.3 ITS Deployment

Boston had a relatively early start with planning for ITS deployment. According to the Regional Transportation Plan, the MPO has participated in ITS activities since 1992 (Central Transportation Planning Staff 2003, p 2-7). In January of 1994, the Massachusetts Executive

\textsuperscript{192} Although one could argue that the \textit{application} of these criteria can be "objective," there is no objectivity in either deciding upon criteria – air quality, land use impacts, economic impacts, environmental justice – and applying weighting factors to those criteria, which are inherently value-laden processes.

\textsuperscript{193} However, Foy does continue to support the Red Line-Blue Line connector project. CLF continues to challenge the state on its failure to meet the original transit agreements. Mac Daniel, "State Set to Endorse 3 Railway Projects," \textit{The Boston Globe}, November 21, 2005, Metro/Region p. A1.

\textsuperscript{194} Indeed, the most "problematic" monitors for ozone exceedances are south of Boston – in the rural towns of Truro and Fairhaven near Cape Cod. Emissions and air quality modeling has indicated that those monitoring stations are primarily affected by emissions from other upwind states, and additional transportation control measures, both in those communities and in Boston, would not serve to bring the area into attainment more quickly. Massachusetts Department of Environmental Protection (2002). 2002 Eastern Massachusetts Supplement to the July 1998 Ozone Attainment Demonstration State Implementation Plan Submittal: Final Submittal, September 6, 2002. Boston, MA, Bureau of Waste Prevention, Division of Planning and Evaluation.
Office of Transportation and Construction and MassHighway had already developed an IVHS Strategic Plan for Metropolitan Boston through a consultant, JHK & Associates. This plan established the goals of improving efficiency, alleviating congestion, reducing fuel consumption and pollution, improving reliability, safety and overall mobility (James H. Kell & Associates 1994). The focus of this strategic plan was to provide “seamless” integration between agencies and modes. At the heart of the recommended regional architecture, was a Regional Transportation Information and Coordination Center (TICC), which was to link the various freeway and arterial traffic management centers, transit management centers, signal systems, and incident/emergency response services. According to this concept, each agency would make “operational and control decisions ....[that] consider the current conditions and potential impacts on the other agencies’ facilities” (James H. Kell & Associates 1994, p 3). With its IHVS Strategic Plan, Boston was also one of the first cities to submit an Early Deployment Plan, and the first city to develop a Regional Architecture (DeBlasio, Eichenbaum et al. 1997, Appendix G). Nevertheless, many of these early expectations quickly encountered difficulties in deployment, and for some observers, ITS deployment and integration in the Boston region has been “disappointing,” at least on the highway and arterial management side (FHWA interview, 2005). Yet, the outlook for ITS applications in transit has been more optimistic, as will be discussed below.

5.6.3.1 Traffic

Probably the most sophisticated freeway ITS components are found on the 7.5-mile Central Artery/Tunnel. The complexity of the CA/T project, and the need to rapidly and effectively detect and respond to problems in the underground facility required an intensive deployment of both typical freeway management components such as closed circuit cameras for fully redundant camera coverage (400 cameras), loop detectors (1,200), lane control signals, highway advisory radio, and variable messages signs, as well as less common applications such as carbon monoxide sensors (120), computer-controlled ventilation buildings, and detection of vehicle overheight for the tunnels (Central Transportation Planning Staff 2003, p 2-8). All of these systems combined are referred to as the Integrated Project Control System, with the core being the Operations Control Center, located in South Boston at the entrance to the Ted Williams Tunnel. The IPCS has been called “nation’s largest, most sophisticated, and most expensive system” representing an investment of over $200 million.195

Looking beyond the CA/T, for freeway management MassHighway and MassPike monitor road conditions with loop detectors, cameras, and wireless communications, and provide traveler information through variable message signs. MassHighway also operates a Regional Traffic Operations Center for monitoring traffic on the highway system, as well as providing emergency patrol vans for incident management. There are also plans to upgrade the dispatching of the patrol vans using AVL capability. A motorist assistance program has been in operation since 1991, and was expanded in 1993, and expanded again using CMAQ funding in 1996. In 1998,

the FAST LANE electronic toll collection system was deployed along the Massachusetts Turnpike, and is installed at Ted Williams Tunnel, Sumner/Callahan Tunnel, and Tobin Bridge. This system is also interoperable on all EZ-Pass equipped toll facilities in the Northeast – including New York, New Jersey, Delaware, Maryland, Pennsylvania, West Virginia, Virginia, New Hampshire, Maine, and Illinois.\footnote{See \url{www.masspike.com} for the current list of EZ-Pass interoperable systems. Last accessed November 22, 2005.}

The City of Boston is the major municipal player in local traffic management, controlling 800 traffic signals. The Traffic Management Center, located in City Hall, controls a network of 380 signals, along with loop detectors and video cameras, that assist both real-time traffic monitoring and management, as well as emergency coordination. The City has been upgrading its TMC, with an investment of $3.2 million, a substantial portion of which comes from CMAQ funds (Boston Transportation Department 2003, p 83). There are also plans to interconnect more signals, install pan-tilt-zoom cameras, and expand its fiber optic network. Waltham and Cambridge and other municipalities also have centralized signal systems (James H. Kell & Associates 1994).

However, deployment of highway and arterial ITS has not nearly reached the levels anticipated by the 1994 Strategic Plan. Looking at the ITS deployment tracking results for Boston, with the exception of on-call service patrols and fixed-route vehicles accepting electronic fare payment, Boston is below the national average for deployment levels (Gordon and Trombly 2003). Some interviews cited early failures in the project management process, specifically, the quality of services that were contracted as a result of accepting the lowest bidder. While interviewees point to examples such as the Regional Traffic Operations Center as successful ITS deployments, the early vision of a central coordinating body, the “Transportation Information and Coordination Center” for seamless integration, has not materialized. Instead, coordination has come about on a case-by-case basis, depending upon the specific technologies and needs of the agencies.

5.6.3.2 Transit

While arterial and freeway management has lagged behind the early expectations set out in the 1994 IVHS Strategic Plan for the Boston region, in recent years, the MBTA has recently undertaken substantial experimentation and innovation with ITS. The MBTA’s innovation has occurred on several fronts. On the technological front, the MBTA is moving toward the deployment of automated fare collection in the form of both magnetic strip cards for both passes and stored value as well as contactless Smart Cards, as well as the interconnection of the various stations through fiber optic for improved communications and support of the automate fare collection technology. While originally conceived in a more narrow sense of simply automating transactions, these technologies have enabled more fundamental organizational changes to occur, the first, a procedural innovation, and the second, a more strategic change in the organization’s culture. First, the interconnection through fiber optic of the various stations on the subway network led upper management to think about new ways to manage the stations, taking advantage of the improved ability to communicate and share information and data in real-time between stations. For example, the video from multiple stations could be shared, and functions
such as station monitoring could be consolidated into fewer stations, with one station monitoring 10-15 stations at one time. These procedural innovations were collectively brought under the umbrella of what is called the “station management initiative” (MBTA interview, 2005).

The adoption of automated fare collection technology also prompted an important shift in the MBTA toward a more customer-service oriented organizational culture. For example, by automating the fare collection process, the personnel staffing the fare collection booths could be freed up from the process of selling tokens and making change, and have more of a presence throughout the stations, both for improved accessibility to the passengers, and, in the post-September 11th environment, for a more active role in station security. The deployment of the AFC is still underway, and the full transformation to the new customer-service culture has yet to fully make its way from upper management to the operators and station employees, the progress to date points to substantial organizational innovation as a result of the adoption and deployment of new technologies. Ironically, the organizational change is occurring as a result of the deployment of this new technology, is more “innovative” than the current technology itself, which is an older technology (magnetic-strip stored-value cards).

With the new Silver Line, the MBTA has also adopted automatic vehicle location (AVL) technology using global positioning systems (GPS) in its buses to better schedule and manage fleet operations through its recently upgraded Bus Operations Center. In its Program for Mass Transportation, the MBTA has identified as a high priority project the installation of AVL throughout the fleet, automatic passenger counters on about 10-15% of the fleet, and bus information kiosks at certain routes and stops (Central Transportation Planning Staff 2003, p 5B-7). As will be discussed below, signal priority has become a higher “priority” as it was incorporated in the Administrative Consent Order (ACO) for the SIP and CA/T transit legal commitments.

5.6.3.3 Information and Other

SmarTraveler, which is sponsored by MassHighway, serves as the region’s core traveler information service. Information on traffic conditions is gathered from cameras, vehicle probes, monitoring of radio frequencies for emergency vehicles, and through direct communications to the various transportation and emergency response agencies in the region. SmarTraveler provides real-time traffic information and more limited transit information free of charge to travelers.

The MBTA provides static traveler information – schedules, maps, fares – through its website, and interactive kiosks at the South Station Transportation Center. Real-time information is currently only available for the Silver Line, with kiosks at bus stops on Washington Street which provide bus arrival information. Automated trip planning functions will “likely” be added to the MBTA’s website in the future (Central Transportation Planning Staff 2003, p 2-13). However, the provision of more real-time information, such as bus arrival times accessible either at

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197 Currently, the MBTA is deploying the CharlieTicket, a rechargeable magnetic-strip ticket for stored value or passes. The CharlieCard, a contactless smart card, will be deployed for general public use beginning in 2007.
bus/subway stations or on the internet, will depend upon the rate of deployment of AVL in the bus fleet.

A limited number of TDM strategies are also supported by ITS applications. For example, RideSource, which is operated by CARAVAN, a private, non-profit organizations funded by MassHighway and FHWA, has a toll free information line and website\textsuperscript{198} for commuting options. The website provides an on-line ride matching service based upon commute preferences.

5.6.4 ITS-Air Quality Links

5.6.4.1 Projects

The air quality transit mitigation projects for the CA/T have had some interesting consequences for the shape of ITS deployment in Boston. Although a number of the commitments have been completed, as noted earlier many still under construction or in planning. While earlier transit projects were almost exclusively capital expansions, there has been a slight shift toward service improvements through operational strategies, including ITS-based improvements. The 2005 Transit Commitments Status Report includes ten projects, three of which have major ITS components: the Urban Ring, Silver Line Service, and Signal Prioritization.\textsuperscript{199} Specifically, these transit projects will rely on ITS components typical of Bus Rapid Transit,\textsuperscript{200} including AVL, real-time information about bus arrivals at stations, and signal priority. For example, the MBTA and MassHighway have been implementing signal prioritization for the Silver Line in cooperation with the Boston Transportation Department (BTD). Priority at key intersections is requested by the MBTA’s control system, and sent to the BTD, which decides whether to grant priority based on several factors: whether priority has recently been given, the presence of emergency response vehicles, and traffic conditions on cross streets. According to the 2005 Transit Commitments Status Report, the Signal Prioritization project could benefit for additional segments of the Silver Line, such as the D-Street crossing, the on-street branches of the Green Line, and other high volume bus routes such as the regular and Cross-Town (express service) buses that service Massachusetts Avenue. Although the initial work on signal priority has been carried out with the Boston Transportation Department, expansion of signal priority to other routes would possibly require collaboration with other cities, such as Cambridge, or agencies, such as Massport for the D-Street crossing of the Silver Line (Massachusetts Executive Office of Transportation 2005). Another example is the Orange Line, where the transit commitment is to increase the capacity on the line. While part of this capacity increase will be from the purchase of additional trains, another key component are the signal improvements need to allow for improve headway control and more frequent service (Massachusetts Executive Office of Transportation 2005).

\textsuperscript{198} Available at \url{www.commute.com}. Last accessed February 12, 2006.
\textsuperscript{199} The “Orange Line Improvements” SIP measure in the Transit Commitments Status Report also includes improved signaling. However, because this is heavy rail, we do not include it, as the definition of ITS generally excludes rail communications and signaling technologies.
\textsuperscript{200} With the exception of the Orange Line, which is a heavy rail line.
In some cases, ITS has come to play an important role in the attempt to find more feasible and cost-effective alternatives to the original agreements, utilizing primarily operational improvements instead of capital improvements. For example, in applying the new objective criteria to the CA/T transit commitments, it was found that the Arborway Restoration project had “the lower user benefit and cost effectiveness calculation of any evaluated” (Massachusetts Executive Office of Transportation 2005). This project was intended to provide non-stop service from the Arborway/Jamaica Plain neighborhoods to downtown Boston, thus “restoring” the original service that was provided on the E-Branch of the Green Line. This streetcar rail service was active until 1985 when service was discontinued, with the E-Branch now ending at Heath Street station. Since that time, the streetcar service has been replaced by regular bus service (Route 39). Restoring the Arborway would require replacement of track, catenary and power systems, new station platforms, and acquisition of vehicles to service the route, with a construction cost of $95 million and operating cost of $2.8 million per year. The EOT and MBTA have attempted to substitute for the project with other projects of greater air quality benefits, while in the meantime, the MBTA has improved the existing service along the original Arborway route. This improved bus service has included the use of new, low platform, 60-foot articulated CNG buses, and the MBTA plans to work with the City of Boston to implement bus signal priority along the route to further improve travel times and service (Massachusetts Executive Office of Transportation 2005).

5.6.4.2 Funding

As a “serious” ozone non-attainment area, the Boston area does not receive the same level of CMAQ funds as “severe” or “extreme” non-attainment cities such as Houston and Los Angeles. Yet, despite the fact that CMAQ is a relatively small portion of federal highway funding in Massachusetts, because most federal funding has been absorbed by the CA/T in recent years, the CMAQ category has become an important funding source for many smaller scale, regular transportation improvements that have been in the planning pipeline for many years, but have not been able to secure funding. According to interviewees, the highway department had been trying to gear most of the CMAQ funding toward road projects that could be determined to be eligible according to air quality benefits. As a result of this process for allocating CMAQ funding, there has not be a strong effort to look for innovative ways to spend CMAQ funds (MBTA interview, 2005). It may also lead to the use of CMAQ funds for projects that are technically eligible for CMAQ, but inappropriate projects from the viewpoint of air quality.

Indeed, the Citizens’ Advisory Council to the Boston MPO expressed a number of concerns with the process for allocating CMAQ funds to individual projects.

“The Advisory Council is concerned about the process used to select this year’s projects as it relates to the CMAQ goals and the readiness of CMAQ and non-CMAQ projects. Targets need to be better defined and the CMAQ process needs to be more open. It should possibly be pulled into the MPO process, with meetings easier to attend, eligibility

201 Specifically, the proposal to make the improved Arborway bus service permanent is discussed in a letter from John Cogliano, Secretary of Transportation, to Commissioner Robert Golledge, Department of Environmental Protection, dated May 18, 2005.
requirements made clearer, and selection criteria more objective. Benefit/cost ratio analysis information or other measures of effectiveness should be provided; air quality analysis should be performed for the present case, not one or ten years into the future. An example of this is the Burgin Parkway Project and its relative cost compared to other eligible projects. While supporting this project, the Advisory Council is concerned about the process used in its selection, and the sense that its CMAQ eligibility and readiness has taken precedence over its evaluation ratings202 (italics added).

The comments raised by the Citizens’ Advisory Council highlight issues of transparency and accessibility in the CMAQ planning process, and also point to the lack of project evaluation and prioritization for CMAQ funds. The current emphasis is on whether a project is ready and eligible for CMAQ funds, not whether is it a good use of CMAQ funds for congestion and air quality purposes. Yet, there are pressures from the Executive Office of Transportation for the MPOs in Massachusetts to develop more a formal CMAQ program for the allocation of those funds, including CMAQ funding targets for each MPO, requests for proposals, and specific criteria for project selection. With more “creative” suggestions for CMAQ funds, some observers believe more CMAQ funds will likely be used for more ITS projects (MBTA interview, 2005).

In terms of categories, the most heavily funded CMAQ projects currently are bike and pedestrian projects (46% of total CMAQ funding), transportation system management (43%), transportation demand management (6%), transit and ITS (with 2% each) (Central Transportation Planning Staff 2005). The largest single project appearing in the current TIP is the Burgin Parkway in Quincy, a $14.4 million project that has been in the planning since the early 1990s to relieve congestion at an important interchange near both Interstate 93 and State Highway 3 (also near the Quincy Adams MBTA station on the Red Line). This project was the main source of concern of the Citizens’ Advisory Council, as discussed above, although the unease was related more to the selection process than the project itself. The Burgin Parkway alone uses more than the annual $10.4 million CMAQ target. Because of the size of the project, this is the only CMAQ-funded project with the air quality benefits modeled using the MPO’s regional transportation project. All other projects use “off-model” calculations203 of emissions changes using basic assumptions regarding changes in travel time, speed, and delay.

The current TIP for the Boston region includes CMAQ projects for fiscal years 2006-2008, with a CMAQ target of $10.7 million annually. Table 5-17 shows all CMAQ-funded projects in the current TIP, with their share of federal CMAQ funds, and additional contribution from state, local or MBTA funds.

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203 This refers to calculations of emissions changes that are not incorporated into the full transportation modeling framework for transportation demand, network flows, and emissions, i.e. the process used for transportation conformity determination.
### Table 5-17 CMAQ-funded projects, FY 2006-2008

<table>
<thead>
<tr>
<th>Project Description</th>
<th>Category</th>
<th>ITS</th>
<th>AQ modeling</th>
<th>Funding (millions of dollars)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Federal</td>
</tr>
<tr>
<td>Franklin Street</td>
<td>TSM</td>
<td>No</td>
<td>Off-model</td>
<td>336,000</td>
</tr>
<tr>
<td>Burgin Parkway</td>
<td>TSM</td>
<td>No</td>
<td>Model</td>
<td>14,400,000</td>
</tr>
<tr>
<td>Route 28 (Main Street)</td>
<td>TSM</td>
<td>No</td>
<td>Off-model</td>
<td>1,600,000</td>
</tr>
<tr>
<td>South Bay Harbor Trail</td>
<td>Bike/Ped</td>
<td>No</td>
<td>Off-model</td>
<td>3,080,000</td>
</tr>
<tr>
<td>Upper Charles Trail, Phase 2</td>
<td>Bike/Ped</td>
<td>No</td>
<td>Off-model</td>
<td>2,400,000</td>
</tr>
<tr>
<td>Boston Traffic Management Center Operations</td>
<td>ITS</td>
<td>ITS</td>
<td>Off-model</td>
<td>916,000</td>
</tr>
<tr>
<td>Regional TDM Program</td>
<td>TDM</td>
<td>Enhanced</td>
<td>Off-model</td>
<td>600,000</td>
</tr>
<tr>
<td>Regional or local shuttles, TMAs, or other TDM</td>
<td>TDM</td>
<td>Enhanced</td>
<td>Off-model</td>
<td>1,560,000</td>
</tr>
<tr>
<td>Suburban Mobility Improvement Program</td>
<td>Bike/Ped</td>
<td>No</td>
<td>Off-model</td>
<td>1,409,600</td>
</tr>
<tr>
<td>Bicycle Parking Infrastructure Program</td>
<td>Bike/Ped</td>
<td>No</td>
<td>Off-model</td>
<td>3,512,000</td>
</tr>
<tr>
<td>Bruce Freeman Memorial Bicycle Path</td>
<td>Bike/Ped</td>
<td>No</td>
<td>Off-model</td>
<td>3,520,000</td>
</tr>
<tr>
<td>Tri-Community Bikeway</td>
<td>Bike/Ped</td>
<td>No</td>
<td>Off-model</td>
<td>3,520,000</td>
</tr>
<tr>
<td>MBTA Bus Emissions Monitoring &amp; Control Program</td>
<td>Transit</td>
<td>Enhanced</td>
<td>Off-model</td>
<td>880,000</td>
</tr>
<tr>
<td>Remote sensing for emissions monitoring</td>
<td>Transit</td>
<td>Enhanced</td>
<td>Off-model</td>
<td>880,000</td>
</tr>
<tr>
<td>TOTAL</td>
<td></td>
<td></td>
<td></td>
<td>37,733,600</td>
</tr>
</tbody>
</table>

Source: (Central Transportation Planning Staff 2005)

At least in terms of funding priority, ITS ranks low among the mix of CMAQ projects. For the fiscal year 2006-2008 period, the only ITS project per se, is the operation of the Boston Traffic Management Center. The CMAQ funds will be used to expand operations, specifically, the addition of four staff engineer positions to operate during the full weekday, from 6AM to 10PM (currently operations are from 7AM to 7PM). According to the City of Boston’s proposal for the CMAQ funds, the TMC will address two major causes of congestion – vehicle breakdowns and double parking, and delays in correcting signal malfunctions – by enhancing response times to these events (City of Boston 2005). Although the Boston Traffic Management Center is the only clearly ITS project, the various TDM strategies could also be enhanced by ITS, in particular, flexible-route shuttles, vanpools and carpools (which could be supported by online ride-matching and in-vehicle route guidance), as well as the MBTA bus emissions monitoring and control program for MBTA buses. Real-time information on transit vehicle emissions would represent an Energy and Emissions ITS application similar to those described in Chapter 2.

Although recent TIPs do not place much emphasis on ITS, earlier TIPs indicated the possibility for substantial emissions reductions from ITS. Looking at the emissions reductions from CMAQ projects in the TIP for 1996-8, ITS and ITS-supported projects contributed to 311 kg/day of VOC reductions (64% of total) and 89 kg/day of NOx reductions (26% of total) in 1999.

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204 For example, the bus emissions monitoring program can use drive-by remote sensing technologies to measure emissions of MBTA buses as they enter or leave a depot or garage. Carolyn Y. Johnson, “MBTA eyes testing bus emissions,” The Boston Globe, September 27, 2004. More advanced applications, such as those described in Chapter 2 in the section on Energy and Emissions ITS applications, could couple AVL with on-board diagnostics and monitoring of emissions, giving more real-time information on emissions or failures of emission control equipment.
Table 5-18  CMAQ project emissions reductions, 1996-1998 TIP

<table>
<thead>
<tr>
<th>Project</th>
<th>Category</th>
<th>VOC reductions (kg/day in 1999)*</th>
<th>NOx reductions (kg/day in 1999)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Logan Airport Remote Parking</td>
<td>Park &amp; Ride</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Southeast Expressway</td>
<td>HOV</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Clean Cities</td>
<td>Alt. Fuels</td>
<td>9</td>
<td>14</td>
</tr>
<tr>
<td>Incident Management</td>
<td>ITS</td>
<td>82</td>
<td>49</td>
</tr>
<tr>
<td>Motorists Assistance</td>
<td>ITS</td>
<td>16</td>
<td>9</td>
</tr>
<tr>
<td>Park &amp; Ride</td>
<td>Park &amp; Ride</td>
<td>89</td>
<td>129</td>
</tr>
<tr>
<td>TMA Formation and New Initiatives</td>
<td>TDM</td>
<td>15</td>
<td>22</td>
</tr>
<tr>
<td>Old Colony Commuter Rail Extension</td>
<td>Transit</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Transportation Demand Management</td>
<td>TDM</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td><strong>1996 projects subtotal</strong></td>
<td></td>
<td>211</td>
<td>223</td>
</tr>
<tr>
<td>Logan Airport Remote Parking</td>
<td>Park &amp; Ride</td>
<td>44</td>
<td>65</td>
</tr>
<tr>
<td>Southeast Expressway</td>
<td>HOV</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Clean Cities/Clean Fuels</td>
<td>Alt. Fuels</td>
<td>10</td>
<td>19</td>
</tr>
<tr>
<td>TMA Formation and New Initiatives</td>
<td>TDM</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>IVHS Traffic Operations Center</td>
<td>ITS</td>
<td>213</td>
<td>31</td>
</tr>
<tr>
<td>Transportation Demand Management</td>
<td>TDM</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td><strong>1997 projects subtotal</strong></td>
<td></td>
<td>267</td>
<td>115</td>
</tr>
<tr>
<td>Congress St. Pedestrian Overpass</td>
<td>Bike/Ped</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Clean Cities</td>
<td>Alt. Fuels</td>
<td>8</td>
<td>11</td>
</tr>
<tr>
<td>Transportation Demand Management</td>
<td>TDM</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td><strong>1998 projects subtotal</strong></td>
<td></td>
<td>8</td>
<td>11</td>
</tr>
<tr>
<td><strong>1996-1998 PROJECTS TOTAL</strong></td>
<td></td>
<td>486</td>
<td>349</td>
</tr>
</tbody>
</table>

*Reductions are not shown because they are incorporated into the MPO's transportation demand model and reported with total regional emissions, or information on emission changes was not available.

Source: (McGahan 1995)

Individual projects are typically on the order of a few million dollars. TDM programs and bike and pedestrian projects are easily cast as typically falling into this funding category, and therefore tend to be the most prominent in terms of the number of projects funded. In addition, TSM projects, such as major intersection improvements or roadway reconfigurations – in particular, projects that have long been waiting for funding are often “backed into” the category (MBTA interview, 2005), serving as a catch-all funding source for relatively smaller roadway projects that can be shown to have emissions benefits from congestion mitigation. However, it will be interesting to see how the mix of CMAQ-funded projects change in the future, if more consistent methods are used for project selection and prioritization.

5.6.4.3 Evaluation

Perhaps not surprisingly, given the limited number of ITS projects that have been used for air quality improvements, evaluations of the emissions impacts of ITS have been undertaken on a relatively ad hoc basis. There has been some evaluation of ITS within the context of CMAQ, as discussed earlier. Yet, the evaluation process and methodologies for measuring emissions
reductions from ITS-based projects have not been formalized as in the case of Houston, for example. Because CMAQ funds are a relatively small funding category, and ITS is not a major component of CMAQ funding, the need to document the emissions impacts from ITS is not as evident as in other cities.

Evaluation of the air quality benefits of ITS seemed to be a more prominent goal at the time of the writing of the Boston Region IVHS Strategic Plan than it is currently. For example, the 1994 Strategic Plan included an appendix that documented the emissions reductions from the two phases of the plan. The analysis modeled the emissions benefits from an incident management program, including a Traffic Operations Center and motorist assistance and incident response. The core modeling assumption was that there would be a ten-minute reduction in detecting, verifying and responding to incidents (McGahan 1995). According to the results in the Strategic Plan, the first phase of deployment would reduce VOC by 190 kg/day and NOx by 40 kg/day, while the second phase would provide additional reductions of 120 kg/day for VOC and 50 for NOx (James H. Kell & Associates 1994; McGahan 1995).

Another early evaluation of an ITS application in the Boston region was the 1993 SmarTraveler air quality study (Tech Environmental Inc. 1993). Indeed, this is a widely cited study both by interviewees in agencies in Boston, and elsewhere, as it is one of the few studies of the impact of traveler information on air quality based on a real system. Based on travel surveys regarding usage of traveler information, the modeling assumption was that 30% of daily callers would change their travel plans based on information from SmarTraveler. It was calculated that the adjusted traveler behavior reduced VOCs by 498 kg/day and NOx by 25 kg/day. However, “daily callers” represented only a small fraction of all drivers on the road. Comparing these results to the CMAQ projects discussed earlier (see Table 5-18), it is noteworthy that the VOC emissions from SmarTraveler alone, are greater than all CMAQ projects during a three year period. However, as discussed in Chapter 2, because the full study could be not accessed, it is difficult to comment on the validity of the modeling approach.

Because some of the more important advances in ITS have been for transit, evaluation is difficult since ITS operational improvements are often highly integrated with other transit service expansions and enhancements. Therefore, measuring the contribution of ITS improvements to overall changes in ridership (and resulting changes in VMT and emissions) is nearly impossible. In fact, the MBTA does not attempt to measure the ridership impacts or air quality impacts of ITS, although it suggests that “overall, Intelligent Transportation Systems could improve passenger perceptions of bus service and make bus service more attractive” (Central Transportation Planning Staff 2003, p 5B-7).

Finally, it is interesting to note that there has apparently been no evaluation of the emissions impacts of the implementation of FAST LANE, although this could be an important source of emissions changes given that the FAST LANE allows vehicles to travel through the toll plaza

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205 The first phase included deployment within Route 128, while the second phase contemplated deployment out to I-495.

without having to come to a full stop. In addition, ETC is one of the ITS applications for which studies of emissions changes are most commonly undertaken, because of the localized nature of the application and ability to measure emissions.

5.6.5 Summary

Major highway expansion in Boston seems to have come to an end, at least for the near future, with the completion of the CA/T. The financial and political pressures stemming from the CA/T project and its cost escalation, as well as a trend of relatively slow population growth in the region, has forced a shift to system maintenance and preservation. However, ITS has not been a major component of that shift away from expansion-based strategies. Although there were ambitious plans in the early 1990s for regional ITS, difficulties in the initial deployment of important highway ITS components to a large extent undermined the high-level support for further initiatives.

Yet, there has been a move toward greater support of transit expansion and enhancement, and the indications are that ITS will be key aspect of that, from the Silver Line to the Urban Ring, and from fare payment to fleet management. In terms of air quality strategies, transportation control measures and transit projects have been at the core of the SIP submittals during the 1990s, and even before the 1990 CAAA. However, a number of projects were committed to not only via SIP commitments, but were legally required as part of the approval and permitting process for the CA/T project. These essentially political commitments have locked the MBTA into a number of transit projects, many of which no longer fit with the MBTA’s current priorities based on a more objective criteria for project evaluation. Yet, an unexpected consequence of these transit commitments, is that for certain projects, ITS components have been incorporated as a way to meet legal commitments for transit projects, while doing so in a more cost-effective manner.

CMAQ has played an interesting role compared to other cities. In the absence of a formal project selection process, and due to the constrained financial situation created by the CA/T project, this funding category has been more of a catch-all category for regular transportation improvement projects that could be found eligible for these funds. As a result, more innovative proposals for the use of CMAQ funds, were eschewed for roadway projects deemed to be more urgent. Nevertheless, a number of important ITS projects have been funded by CMAQ – projects that might not have been funded otherwise given the situation created by the CA/T. Regarding CMAQ funding of ITS projects, one interview suggested, “I sense that the demand is so great for traditional transportation projects, that if there wasn’t the CMAQ program or enhancement categories, [ITS] would be a lower priority” (MBTA interview, 2005). Therefore, CMAQ program seems to have lead to a funding portfolio that is slightly more “balanced” that might have been otherwise if CMAQ funds had not been available.

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207 Although there may have been internal evaluations, there appears to be no publicly available studies on the air quality impacts of FAST LANE.
Although the history outlined above highlights a number of connections between air quality issues and ITS deployment in Boston, the levels of experimentation and innovation with ITS as a tool for emissions reductions and air quality improvements have been highly limited. This is also reflected in the relative scarcity of studies of emissions changes from ITS deployments, and the lack of specific procedures and methodologies for measuring and modeling emissions impacts of ITS. While the early ITS Strategic Plan, at least in its rhetoric, placed an emphasis on the air quality benefits of ITS deployment, that focus was diminished in the following years, with very few ITS projects, perhaps with the exception of CMAQ projects, using air quality benefits to either justify projects or increase support.
5.7 ORLANDO, FLORIDA

5.7.1 Background

5.7.1.1 The City

With a population of 1.6 million, Orlando is a medium-sized city, and the second smallest of the five cases in this thesis. In addition to being a major tourist destination, Orlando also hosts many corporate headquarters, manufacturing, research, and regional distribution centers (LYNX 2005, p 2-2). The Orlando Metropolitan Area encompasses three counties – Orange, Osceola, and Seminole – with Orange County being home to approximately 1 million residents, and the other approximately half million residing in Seminole and Osceola Counties. During the 1980s and 1990s population growth was strong, with an average annual growth rate of 3.6% between 1980 and 2002 (author's calculations from LYNX 2005). During that time, this low-density city expanded rapidly, first into the bedroom community of Seminole County, and then into the more rural area of Osceola County, which nearly doubled its population during the 1990s. According to the 2025 Long Range Transportation Plan, population is expected to continue to increase by 2% annually, bringing the population up to 2.2 million by 2025, while tourism is expected to grow even more rapidly, with 5% annual growth in the number of visitors, resulting in a 71% increase of VMT compared to current levels (METROPLAN Orlando 2004, p 1-1).

5.7.1.2 Transportation

Orlando is an auto-oriented city, with a small share of trips (between 3-4% of all vehicle trips) being served by transit. North-south traffic flow is highly concentrated on Interstate 4 (I-4), in part because of the lack of alternate routes. Going east-west through Orlando are several tolled expressways, with various segments of the same roadways operated by both the Orlando-Orange County Expressway Authority (OOCEA) and the Florida Turnpike Enterprise. A large percentage of freeway miles in Orlando are tolled, which, as will be discussed later, translates into a more customer-service oriented freeway system.

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208 Currently there is a toll road beltway (operated by OOCEA and Florida Turnpike) to the east of the city, and the long-term plan is to construct a “western beltway” around Orlando.

209 Osceola County also operates the Osceola Parkway, a short stretch of toll road (approx 12 miles) leading directly into the Walt Disney World Theme Park.
Nearly 43 million tourists visit central Florida every year. Because of its numerous tourist attractions, Orlando has a large private sector transportation market in terms of shuttle and bus services between hotels and the various tourist attractions, or in the case of Walt Disney World, the famous monorail that connects the various Disney “Kingdoms” and resorts. However, many of the visitors to Orlando also rent cars. Therefore, while an important base for the economy, the tourist industry also places heavy demands on the transportation network.210

Public transit in Orlando is mainly served by fixed route buses, with typical headways of 30 or 60 minutes. The public transit service provider, LYNX, served approximately 22.7 million passenger trips in 2003, with ridership growing relatively steadily (for example, ridership in 1993 was only half of 2003 levels at 11.1 million). In addition to bus service, there have been important steps taken in developing a light rail plan beginning in the mid-1990s. However, major setbacks have occurred due to failures to reach consensus regarding the alignment of the

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210 The tourism industry and theme parks also create unique traffic patterns, with additional “peak” periods, for example, a late evening peak when the parks close and tourists and employees leave.
light rail line, as well as problems securing local funding. More recently, project development and environmental impact studies were begun for the North Orange/South Seminole Intelligent Transportation Systems/Bus Rapid Transit (FlexBRT) project, possibly indicating a shift in preferences from light rail to a more “flexible” BRT system. The future Transit Vision adopted through a Joint Work Session between LYNX and Metroplan included a mix of modes, with expansion of the bus system, Bus Rapid Transit, Light Rail, and Commuter Rail (LYNX 2005). However, whether the funding can be secured to support this ambitious transit expansion is yet to be determined.

### 5.7.1.3 Institutions

In terms of freeway travel, the Florida DOT, Florida Turnpike Enterprise, and the Orlando-Orange County Expressway Authority (OOCEA), are the main players in Orlando, and have typically taken the lead on many of the ITS deployments in Orlando. Traffic management on arterial streets is the domain of the three counties – Orange, Seminole and Osceola – with various levels of participation by the larger cities within the Orlando Metropolitan Area – the City of Orlando, Winter Park, and Maitland.

LYNX’, the public transit provider, operates all fixed-route bus service, coordinates ride-matching for carpools, vanpools, and School Pools, the Road Rangers program for roadside assistance, and paratransit services, and a downtown circulator called LYMMO.

The designated MPO responsible for transportation planning in the three-county Orlando metropolitan area is Metroplan. There are five committees which directly advise the Metroplan Board. The Transportation Technical Committee is one of the key committees, with planners and engineers for all jurisdictions (cities and counties) and organizations to review and evaluate the transportation plans and programs and make technical recommendations to the Board. There is also a Clean Air Team Subcommittee representing a range of public and private sector agencies and other stakeholders. Although primarily a planning organization, Metroplan has also brought together more operations-oriented staff from various jurisdictions through the creation of a Management and Operations Subcommittee within Metroplan to deal with issues of congestion management, ITS and transportation demand management.

Finally, at the state level, the Florida Department of Environmental Protection is responsible for air quality management for mobile, area and point sources. However, in the absence of non-attainment areas for the entire state of Florida, there is not as direct involvement in local control strategies, which are more typically on a voluntary basis and managed by the MPO.

### 5.7.2 Air Quality History

Orlando has officially been in attainment with national air quality standards since the late 1980s. However, looking back to 1978, Orlando was designated non-attainment for the 1-hour ozone standard. The MPO was required to submit an air quality implementation plan to bring the area back into attainment by 1982, which it was able to do successfully by taking credit for new bus purchases, although the new national vehicle emissions standards and fleet turnover was also a
critical factor (Metroplan interview, 2005). Since that time, the region has come close to exceeding ozone standards once again, nearly falling out of attainment in 1998. Nevertheless, favorable geographic and meteorological conditions in the Orlando and Central Florida area to a large extent keep ozone levels in check during the “ozone season” which lasts from May to October. Located in the central part of the Florida peninsula, Orlando typically experiences heavy afternoon rains when breezes from both the Gulf of Mexico and Atlantic collide over Central Florida, effectively cleansing the air, and avoiding the accumulation of pollution and precursors over various days.

5.7.2.1 Sources

A emissions inventory for the three-county area was completed by a graduate student at the University of Central Florida (UCF), according to the guidelines set by the EPA (Arbrandt 2002). The inventory focused on precursors of ozone, the criteria pollutant of interest, detailing NOx and VOC emissions from all mobile, area and point sources. As seen in Figure 5-25, for both NOx and VOC, on-road mobile sources are the dominant source category, comprising 61% of total NOx emissions and 44% of total VOC emissions in Central Florida (Cooper and Arbrandt 2003).

Figure 5-25 Emissions inventory for Central Florida (2002)

![Emissions inventory for Central Florida (2002)](image)

Source: Data compiled from Tables 5.1-5.4 (Arbrandt 2002)

Compared to an earlier emissions inventory completed by 1996, also done by researchers from UCF, emissions from mobile sources increased substantially, while point and area sources remained roughly the same. VOC emissions from mobile sources increased by 6%, while NOx mobile source emissions increased by 59% over 1996 levels. This growth in mobile source emissions reflects the considerable growth in VMT (61% between 1996 and 2002), demonstrating that growth in vehicle travel in the three-county Orlando metropolitan area outpaced the rate of reduction in emissions factors due to more efficient and cleaner vehicles (Cooper and Arbrandt 2003).
5.7.2.2 Actions

Given its air quality attainment status, not surprisingly, there have been few mandatory actions for reducing emissions from mobile sources. There is no inspection and maintenance (I/M) program for Orlando, although the idea of I/M is wielded as a threat for what might be necessary if the area falls out of attainment. The majority of actions to reduce mobile source emissions are voluntary measures relying on public awareness and involvement. Metroplan sponsors a "Clean Air Day" every May, marking the beginning of the ozone season, in which they bring in alternative fuel vehicles, and attempt to disseminate information on air quality issues to the public. For example, Metroplan has identified and publicized information on concrete actions the public can take to reduce emissions, including: trip chaining, ridesharing, properly maintaining vehicles, walking or bicycling, limiting vehicle idling, and telecommuting. However, the success of these transportation demand measures depends on the awareness and personal initiative of drivers. LYNX has also been involved in supporting measures that promote both transit use and ridesharing: such as an online application for matching rideshares, support of vanpools with LYNX vehicles, and Park and Ride lots with co-operated with FDOT.

5.7.2.3 Issues

Although favorable weather conditions have played an important role in maintaining Orlando’s air quality within the NAAQS limits for the most part, there continues to be pressure from Metroplan to keep the issue of air quality on the agenda when looking at transportation plans and projects. During the ozone season, Metroplan staff reports regularly to the board and committees giving updates on ozone levels. To a large extent, Metroplan has looked to the experience in Atlanta, and the conformity problems that led to a freeze in federal funding for major transportation projects. Because the regional forecasts suggest substantial population, employment and VMT growth in the Orlando metropolitan area, the conformity lessons of nearby Atlanta become more relevant.

The impact of OOCEA’s tollway expansion "on environmentally sensitive areas and on urban development patterns into environmentally sensitive areas," have been some of the concerns aired by Metroplan’s Transportation Technical Committee and Citizens’ Advisory Committee (Orlando Orange County Expressway Authority 2000, p 2-7). The response of OOCEA is that it does not “intend to drive local development patterns,” and instead are responding to already adopted local land use plans for the Orlando region (ibid). Managers at OOCEA also consider the continued attention on air quality to be somewhat unnecessary, citing the continuous improvements in Orlando’s air quality. In fact, on its website, OOCEA points to the improvements in air quality in Central Florida, shows air quality trends and comparisons to Atlanta, provides tips on keeping ozone levels down by reducing individual travel, and reports on the emissions reductions from implementation of E-Pass.

211 According to Metroplan, because a politically unpopular annual vehicle safety inspection program was eventually abolished by Governor Robert Graham, any similar inspection program would be very poorly received by politicians and by the public.
5.7.3 ITS Deployment

According to the summary indicators developed by the ITS Joint Program Office for tracking ITS deployment, Orlando ranks high in arterial management, electronic toll collection, coverage of freeways by real-time electronic surveillance and dissemination of traffic conditions to the public. The site visit to Orlando confirmed that deployment levels of ITS were indeed high, and that additional deployment and further integration of existing deployments were also taking place at an aggressive pace. Although not an exhaustive description of the existing ITS applications, some of the key applications are described in more detail below.

5.7.3.1 Traffic

Given its importance in regional traffic flows, much of the ITS initiative for freeway management has centered on I-4, such as camera coverage, VMS, and a Regional Traffic Management Center operated by FDOT. There are also moves toward the use of variable speed control on some segments of I-4, which would enable FDOT to lower the speed limit in response to weather conditions or traffic incidents. Indeed, incident management has been a priority driving many of the ITS deployments in Orlando – 511, VMS, highway service patrols213 – and is a concept that has been embraced by local elected officials in recent years.

OOCEA has been proactive in implementing ITS technologies such as electronic toll collection – a transponder, account-based system called E-Pass. The Florida Turnpike Enterprise later followed with the SunPass.214 With discussions beginning in 1989 to look into new toll collection technologies – anticipating high levels of demand on the expressways and consequently long delays at toll plazas – OOCEA was one of the early adopters of this technology, beginning revenue service at selected toll plazas in May 1994 (Shofner 2001, p 159). The Expressway Authority has also implemented cameras and variable message signs, with plans to expand the coverage of both. However, in order to avoid redundancy in functions between OOCEA and FDOT, the video from OOCEA is sent over to the Regional Traffic Management Center operated by FDOT, where FDOT monitors the video and puts up messages on OOCEA’s variable messages signs. According to OOCEA, the motivation for their ITS deployments is to provide value to the users of their tollways, and while possible improvements to air quality from ETC would be welcomed, the organizational priority is building roads (OOCEA interview, 2005).

For arterial streets, the City of Orlando was one of the early leaders in the late 1980s to establish a Traffic Management Center and coordinate signalized intersections in order to reduce delay. Now, in partnership with Orange County, the City operates and maintains the Regional Computerized Signal System, coordinating 384 signals within Orange County. The City also plans to add additional cameras and possibly VMS. Seminole County, to the north, followed a few years later, with a program of signal upgrades and coordination and installation of fiber optic

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213 The highway service patrol, designated “Road Rangers” is jointly operated by LYNX and FDOT.
214 The SunPass technology was not deployed until 2000. OOCEA and the Florida Turnpike Enterprise had earlier reached an agreement that OOCEA’s E-Pass would make interoperable with the Turnpike’s future ETC system (OOCEA interview, 2005).
communications. Approximately 90% of its 350 signalized intersections are now coordinated in the central system (Seminole County interview, 2005). Seminole County has also been somewhat unique in its implementation of VMS along major arterials, mainly those arterials adjacent to I-4. Osceola County is just beginning with their entrance into ITS, to a large extent following the lead of FDOT and working with Orange and Seminole Counties.

5.7.3.2 Transit

The mode share for transit in Orlando is small. Nevertheless, the transit provider, LYNX, has deployed several ITS applications such as on-board stop announcements and video surveillance on its fixed-route bus service on all 236 buses in the revenue vehicle fleet (LYNX 2005, p 3-7). An FTA-sponsored operational test was conducted in 1999 to test the use of an intermodal smart card for use on the OOCEA expressways, parking garages in the City of Orlando, and on LYNX. Although successful from the viewpoint of organizational coordination, the operational test was limited in scope (involving only 2 of 62 routes for LYNX), and the use of the cards was terminated after the operational test finished. Deployment of a smart card technology does not appear to be a near-term reality. The most ITS-intensive transit service is LYMMO, a free rapid transit system which operates on a 3-mile continuous loop through downtown Orlando. Running as a downtown circulator on a bus-only lane, LYMMO utilizes GPS, silent alarms and on-board surveillance, data archiving and passenger counters (Diaz, Chang et al. 2004, p 2-67). However, probably the more interesting features are the traveler information screens at stations/stops, with monitors displaying maps of the local street network with real-time tracking of the buses on the map itself.

As noted earlier, a study is now underway for the North Orange/South Seminole Intelligent Transportation Systems/Bus Rapid Transit (FlexBRT) project, which would draw heavily on ITS applications. However, this project is still in the early stages of planning and evaluation.

5.7.3.3 Information and Other

One of Orlando’s early ventures into advanced traveler information systems was a operational test for a system called Travel Technology (TravTek). This system represented the prototypical early IVHS vision of an in-vehicle navigation system incorporating real-time traffic conditions for making the optimal route selection. The field operational test was carried out as a public-private venture between the General Motors Corporation (GM), the American Automobile Association (AAA) and the FHWA that began in 1989. Orlando was selected as a operational test site for TravTek because of its role as an important tourist destination, and therefore high rental car usage, as well as the fact that the AAA would be relocating its headquarters to

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215 While the typical spending priorities for cities and counties is to start with traffic cameras, then move to other technologies such as VMS, the Board of Commissioners in Seminole County has disallowed the use of cameras on roadways, citing privacy issues. Therefore, Seminole County is unique in having no traffic monitoring cameras, but relatively extensive VMS coverage.

216 75 of the equipped vehicles were part of a rental car fleet to be used by visitors, while 25 vehicles were used by local residents Science Applications International Corporation (SAIC) (1994). IVHS Institutional Issues and Case Studies: TravTek Case Study. Cambridge, MA, Volpe National Transportation Systems Center,: 37 pages.
Orlando. The concept of TravTek, as well as many of the key system design and project management issues were decided in advance of selection of Orlando as the site for an operational test. However, with GM and AAA bringing in both technical resources and funding, and FWHA providing additional funding, mainly in the form of grants to support the Transportation Management Center, the Florida DOT and City of Orlando were brought on-board to the project.

Partially a result of this field operational test, cooperation between different agencies in the Orlando area has been relatively high since the early 1990s. FDOT and the City of Orlando collaborated in the field operational test for TravTek, with more limited involvement of Orange County (Science Applications International Corporation (SAIC) 1994). Although the TravTek system did not move past the initial operational test, it provided a learning experience to the actors involved a focus to the various agencies in the region to the possibilities of an integrated ITS. Later, working together through Metroplan, the agencies involved in ITS developed an Early Deployment Plan, which was submitted to the FHWA in 1996. According to Seminole County, this was an important effort for defining the ITS vision for the region, and significant in that all of the partner agencies signed off on the plan (Seminole County interview, 2005).

More recently, about 13 agencies signed a consortium agreement to coordinate their ITS efforts, modeling the agreement off of Houston’s TranStar. According to both OOCEA and Seminole County, they were able to effectively leverage that consortium to secure the 10 million dollar federal grant to support the iFlorida for project for advanced traveler information led by FDOT (OOCEA, Seminole County interviews, 2005). The Expressway Authority, OOCEA, has also been proactive in its coordination with other public sector agencies. For example, as part of the iFlorida project, OOCEA will provide arterials speeds by setting up the same transponders used for toll collection to measure travel times.

Even before the iFlorida project began, Orlando was also relatively successful with deployment of its 511 traveler information service, with an average of 100,000 calls per month in 2005. Much of the information is focused on traffic conditions on I-4 and the expressways. With the iFlorida project, the system will be also expanded to include arterials.

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217 GM was the main initiator and champion of the project, and had worked on developing the TravTek design for several years before approaching AAA. TrakTek was essentially the concept of the Electronic Route Guidance Systems (ERGS) developed in the 1960s as part of the research initiative’s carried out by the precursor to the FHWA, the Bureau of Public Roads (BPR). Saxton, L. (2000). History of ITS in Highway Operations. Intelligent Transportation Primer. Washington, DC, Institute of Transportation Engineers. The FHWA would be brought in later, and once agreement was established between GM, AAA, and FHWA, the group went to the City of Orlando and Florida DOT with the Travtek proposal Science Applications International Corporation (SAIC) (1994). IVHS Institutional Issues and Case Studies: TravTek Case Study. Cambridge, MA, Volpe National Transportation Systems Center.; 37 pages.

5.7.4 ITS-Air Quality Links

5.7.4.1 Projects

To date, there have been no ITS projects in Orlando with an explicit link to air quality. Although, the organizations deploying ITS in Orlando generally would like to see emissions benefits from ITS, the primary motivations for those deployments are congestion and safety.

5.7.4.2 Funding

In contrast to the other five case study cities, Orlando receives no CMAQ funding which would tie ITS projects to air quality benefits. Funding for ITS deployments in the Orlando metropolitan area has primarily been through federal grants and the use of STP funds. Local funding has also been important, for example, in Seminole County where a voter-approved 1% sales tax was approved in 1991, and again in 2001, generating nearly 50 million dollars a year for transportation, from which funds can be set aside for ITS (Seminole County interview, 2005).

Metroplan has been also effective in setting aside portions of STP funds for non-highway projects. According to planners at Metroplan, under the pressure of escalating costs for highway expansion, in particular, for acquiring right-of-ways, other non-highway options began to look more cost-effective. There was a sense that they would be "playing a losing game" against traffic congestion by continuing to invest nearly exclusively in highway expansion (Metroplan interview, 2005). The percentage of STP funds going toward non-highway options has continued to increase. For the current TIP, the split is 58% highway, 30% transit, and 12% bike and pedestrian facilities and other transportation enhancements (METROPLAN Orlando 2004, p I-6). In addition, from general highway funds, two million dollars are designated ITS and Congestion Management System (CMS) projects. In future TIPs, that amount will increase to four million (Metroplan interview, 2005).

5.7.4.3 Evaluation

Although there have been no ITS projects with an explicit air quality goal, there have been several detailed assessments of the emissions and fuel consumption changes from ITS applications have been undertaken, most notably, a study of the emissions impacts of E-Pass, and an FHWA-sponsored study of the TravTek field operational test.

Environmental concerns with ITS deployments in the early 1990s seemed to attract little attention, and ranked low on the FDOT's organizational priorities. Citing an analysis of the TravTek operational test:

"A FDOT staff person concluded that there were severe budget and environmental impediments to Florida's participation in the TRAVTEK project. Through high level state support for TRAVTEK, this person was replaced by other FDOT people who believed that TRAVTEK was a priority, [and] the metropolitan planning commission was fully

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As will be discussed later, Tulsa does receive CMAQ funding, however because Tulsa is in attainment, the funds may be used more flexibly as STP funds.
briefed on all environmental issues” (Science Applications International Corporation (SAIC) 1994).

While environmental concerns were apparently not considered to be an important factor in whether or not to undertake the field operational test, ex-post evaluations were completed to assess the emissions impacts. The study, sponsored by FHWA and undertaken by researchers at Queen’s University in Canada, included emissions (HC, CO, NOx) and fuel consumption as four of their nine measures of performance (MOPs). The emissions changes were modeled for various levels of market penetration (LMP) by adapting the INTEGRATION micro-simulation model to the Orlando network characteristics. The model incorporated the routing logic used by the TravTek vehicles to more accurately model the travel patterns of the TravTek-equipped vehicles, but also modeled the background (non-TrakTek) traffic. The results were mixed in terms of the emissions impacts of TravTek. The most straightforward results were for HC, which decreased monotonically with increasing LMP, with a maximum reduction of 16% at an LMP of 100%. The results for CO were non-linear, with emissions increasing slightly (3%) at low LMP, but then decreasing with an LMP greater than 10%, with a maximum reduction of 7% at 100% LMP. Finally, for NOx, the impacts were negative, with emissions increasing for nearly all levels of LMP. The maximum increase for NOx was 5% at an LMP of 30% (Van Aerde and Rakha 1996, pp iv-v, 102-103). These results were from simulation only, and no actual field measurements were made.

At approximately the same time as the TravTek evaluation, another study was undertaken by researchers from the University of Central Florida in order to assess the emissions impacts of electronic toll collection. The project, sponsored by OOCEA, was to simulate scenarios with and without E-Pass, and under different levels of demand. Data was collected on arrivals, departures and speed before the introduction of E-Pass (August-October 1994) and after (July-August 1996), during which the average vehicle volume grew by 30%. The level of usage of E-Pass for the Holland East Toll Plaza – the most heavily used plaza – was 40% for the “after” situation. Emissions rates were derived from the MOBILE5a emissions model, meaning that only speeds, and not acceleration/deceleration events were used to calculate emissions. The simulation results showed that even with increased volume CO and HC fell by approximately 7% from the “before” to “after” scenario. In contrast to the promising results for CO and HC, the picture for NOx was more negative, with significant increases in emissions (34%) due to higher speeds through the plaza (Klodzinski, Al-Deek et al. 1998). Overall, the OOCEA took these results as good news, noting on their website that “Researchers Say E-PASS Reduces Pollution,” pointing to the CO and HC reductions, but omitting the outcomes for NOx. 220

5.7.5 Summary

In terms of ITS, Orlando has had impressive levels both of deployment and levels of integration, with several focusing events – such as the TravTek operational test and iFlorida grant – serving to define a pathway for future ITS deployments, and consolidate coalitions around specific

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initiatives. Orlando has also been able to successfully secure ITS funding both at the federal level, through earmarks and grants, and at the local level with set-asides from STP funds and county-level sales taxes.\footnote{Seminole County is the more fortunate in this respect, with a one-cent sales tax that generates $500,000 per year in dedicated funding for ITS projects alone. Osceola also has a one-cent sales tax for transportation, but directs the spending to other priorities. Orange County has been unsuccessful in passing a similar sales tax.} Although in attainment with air quality, the prospect of high levels of future population and VMT growth and the example of Atlanta's conformity problems and freezes on transportation investment, allow Metroplan to keep the air quality issue on the agenda. Nonetheless, in the absence of air quality conformity requirements, funding sources such as CMAQ requiring consideration of emissions reductions, or pressures from the public to address air quality, there have been no ITS projects with an explicit air quality or emissions component.

Some in-depth evaluations have been done, both pointing to the difficulty in reducing HC and CO emissions without incurring the NOx penalty of higher speeds. Indeed, it is worth noting that both the FHWA and OOCEA perceived a need to measure the emissions impacts of these ITS applications in an area that has historically been in attainment of ozone standards, even if the results of these studies did not lead to specific changes in their ITS deployments.
5.8 TULSA, OKLAHOMA

5.8.1 Background

5.8.1.1 The City

Of the five case study cities analyzed in this research, Tulsa represents the smallest metropolitan area, with a population of approximately 860,000 in 2000. Again, we chose this case to contrast with the larger metropolitan areas with higher levels of ITS deployment, and longstanding air quality problems. It also presented an interesting case as a city which is just beginning to focus on ITS, with few applications actually in place, as well as a city that was on the verge of falling into non-attainment status for the first time since the passage of the 1990 CAAA. Population and employment growth in Tulsa have been relatively slow at just over one percent average annual growth during the 1990s. The region faced major job losses in the 1980s due to sharp downturns in the oil, gas and aerospace industries – the largest employers in the Tulsa region, and has only gradually been recovering in terms of total employment and downtown employment (Indian Nations Council of Governments 2005, p 11).

5.8.1.2 Transportation

Tulsa’s transportation network is a well-organized grid-based arterial network, with major arterials spaced approximately every mile both in the north-south and east-west direction, crossed by several routes such as I-44 (formerly the famous Route 66) and the Broken Arrow Expressway (see Figure 5-26). With only minimal congestion on its network, even during peak hours, congestion is not a critical political issue in the Tulsa area. According to Destination 2030, the long-term regional transportation plan, “Tulsans rely heavily on personal automobiles for transportation” with most commute trips made in single-occupancy vehicles (SOV). An auto-oriented city, VMT continues to grow in Tulsa, with trends showing that residents are making more, although not necessarily longer trips in private autos, while the share of non-SOV trips is declining (Indian Nations Council of Governments 2005, p 11). The daily VMT in the Transportation Management Area was just over 21 million vehicle miles in 2000 (Indian Nations Council of Governments 2005, p 26).
Most transportation investment continues to be focused on construction and maintenance of the highway network, and identifying and improving major bottlenecks. In terms of overall mode split, transit use is minimal (less than 1% of total trips), and primarily serves non-choice riders such as low-income individuals, youth and elderly, and households without access to a private car or truck. Transit system ridership levels fell nearly continuously during the 1990s, from just over 3.2 million riders per year in 1992 to 2.6 million in 2002, with a short upswing in ridership levels between 1998 and 2001 (Perteet Engineering 2003, p 5).

5.8.1.3 Institutions

As a smaller metropolitan area with limited ITS deployment and in attainment with national air quality standards, the number of actors involved directly in transportation and air quality management is less than in other metropolitan areas. However, the generic public sector actors in the region are essentially the same: the city, MPO, transit provider, state environmental agency, and state transportation/highway department. The county governments, in comparison to some of the other metropolitan areas, have not been as involved in ITS deployment.
The designated MPO for the Tulsa area is the Indian Nations Council of Governments, which encompasses all of Tulsa County and portions of Wagoner, Osage, Rogers and Creek Counties. The majority of the population within INCOG's boundaries is located within Tulsa County. The City of Tulsa is the largest city in the area, followed by Broken Arrow, and is responsible for local streets and signal control, and owns and operates Tulsa Transit, the primary public transportation service provider in the Tulsa Metropolitan area. Tulsa Transit currently operates 56 traditional buses along 22 routes (regular, nighttime and express routes) plus demand-responsive service for certain areas (Indian Nations Council of Governments 2005, p 44).

At the state level, are the Oklahoma Department of Transportation (ODOT) and the Oklahoma Department of Environmental Quality (ODEQ), with their primary offices located in Oklahoma City and district offices in the Tulsa area. ODEQ is Oklahoma's state environmental agency, with responsibility for fulfilling the requirements of the Clean Air Act. While ODEQ is responsible for working with INCOG in the development of the State Implementation Plan (SIP) for air quality – including Tulsa and Oklahoma City – ODEQ does not have local offices in Tulsa for mobile source measures.

5.8.2 Air Quality History

For 20 years, Tulsa was a non-attainment area for 1-hour ozone until being re-designated as attainment for ozone just before the passage of the 1990 CAAA. Nonetheless, after having been extent from the obligations required under the more stringent 1990 CAAA, Tulsa recently found itself in danger of returning to non-attainment status under the new 8-hour standard for ozone. According to the INCOG, "air quality planning in the TTMA has intensified as ozone concentrations have exceeded the value permitted by the 8-hour ozone NAAQS" (Indian Nations Council of Governments 2002, p. iv). Although INCOG has lacked the resources to fully analyze the ozone problem at the local level, air quality monitoring in the Tulsa area was initially showing that the area was violating the 8-hour standard with a design value of 87 ppb for the years 2000-2002 (Indian Nations Council of Governments 2002; Makler and Howitt 2003).

5.8.2.1 Sources

Because Tulsa, and indeed the entire state of Oklahoma, has not faced serious air quality problems during the past 10-15 years, few resources have spent on developing modeling capabilities and detailed emissions inventories for local airsheds. Therefore, the exact nature of local ozone formation and whether it is primarily a VOC or NOx problem in the Tulsa region airshed is unclear. According to planners at INCOG, Tulsa's ozone problem is mostly related to VOC emissions, but there are also concerns about NOx from large point sources, since the Tulsa has several power plants in the area, including two new plants built within the past five years (INCOG interview, 2005). According to the 2002 emission inventory for ozone precursors in the Tulsa Metropolitan Area, on-road mobile sources represented 47% of VOCs emissions, 35% of NOx emissions, and 67% of CO emissions (Indian Nations Council of Governments 2005, p 22).
5.8.2.2 Actions

In response to concerns about a pending non-attainment designation, Tulsa entered into an Early Action Compact (EAC) with EPA in December of 2002, based upon the Protocol developed by the Texas Commission on Environmental Quality (formerly the Texas Natural Resource Conservation Commission) in cooperation with EPA. Earlier, Tulsa had also used a similar Flexible Attainment Region (FAR) compact to address possible exceedances of the 1-hour ozone standard. However, despite early signs that Tulsa would probably be in violation of the 8-hour ozone standard, by the time 8-hour ozone designations were actually made by EPA in April 2004 (after years of legal battles at the federal level following initial promulgation of the new standard in 1997) air quality monitoring was indicating that all of Oklahoma was actually in attainment of the standard, with design values of 0.080 ppm for 8-hour ozone. Although the area is in attainment with the standard, and the EAC was, in fact, not necessary for non-attainment designation, the EAC still provides a safety net in case the area exceeds the standard within the next few years. Tulsa's Early Action Compact was a trade-off in which the local air quality planners in Tulsa would commit to developing and implementing certain control strategies to achieve the 8-hour ozone standard by 2007, while in return, the EPA would defer designation of the area as non-attainment until 2007, in the case that air quality monitoring showed the area to be exceeding the 8-hour ozone standard.

Table 5-19 Tulsa Early Action Compact (EAC) milestone commitments

<table>
<thead>
<tr>
<th>Milestone Date</th>
<th>Item</th>
</tr>
</thead>
<tbody>
<tr>
<td>December 31, 2002</td>
<td>Submit signed EAC with milestones</td>
</tr>
<tr>
<td>July 16, 2003</td>
<td>Identify/describe local strategies being considered for use in the EAC Plan</td>
</tr>
<tr>
<td>March 31, 2004</td>
<td>Submit attainment demonstration modeling and plan to State</td>
</tr>
<tr>
<td>December 31, 2004</td>
<td>State submits SIP with the local area plan to EPA</td>
</tr>
<tr>
<td>December 31, 2005</td>
<td>Implement any required rules</td>
</tr>
<tr>
<td>December 31, 2007</td>
<td>Attain the 8-hour ozone standard</td>
</tr>
</tbody>
</table>

Source: (Oklahoma Department of Environmental Quality 2004)

In May 2003, as part of the commitment milestones laid out in the EAC (see Table 5-19), an ambitious list of 23 potential local control strategies was developed by INCOG's air quality committee addressing all sources. Nonetheless, only a limited number of transportation control measures (TCMs), mainly traffic flow improvements, were actually included in the December 2004 SIP for the state. As more detailed photochemical and emissions modeling was undertaken, it became clear that air quality in Tulsa (as well as in Oklahoma City) would continue to improve even in the absence of any local controls. This is primarily due to the

222 "A violation of the 8-hour ozone standard occurs when the average of the fourth highest 8-hour ozone concentration over three consecutive years exceeds 0.084 ppm (84 ppb)" Oklahoma Department of Environment Quality, Revisions to the State Implementation Plan for the Control of Ozone Air Pollution. Tulsa Metropolitan Area 8-hour Ozone Early Action Compact. Submitted to EPA Region VI on December 31, 2004.
reduced emissions from Tier-2 light duty vehicle standards coupled with turnover in the vehicle fleet, along with new rules for heavy duty diesel vehicles and non-road sources, and even control measures being implemented in the eastern US that would reduce the transport of ozone to the Oklahoma region (ODEQ interview, 2005) (Oklahoma Department of Environmental Quality 2004). In the public hearings regarding the EAC, it was highlighted that improved air quality modeling showed that 8-hour ozone levels would be well within attainment by 2007. It was also shown that emissions for VOC, NOx and CO in 2012 would be lower than their 2007 levels, and thus it was argued that Tulsa would continue to be in attainment for 2012 as well.

As a result, the only local control strategies included within the Tulsa EAC — as part of the statewide SIP submitted in December 2004 — were capacity improvement projects and roadway intersection improvement projects. These projects represented a very small portion of the measures identified in INCOG’s May 2003 list of possible control strategies that included I/M programs, idling controls, reductions of speed limits on freeways, vapor recovery and various measures for area sources. In comparison with the May 2003 list, the control strategies actually listed in the final EAC/SIP (designated the Tulsa Area Transportation Emission Reduction Strategy) consist more narrowly of traffic flow improvement projects: targeted roadway capacity expansions, expressways and primary and secondary arterials, and limited number of already planned intersection improvement projects, primarily traffic signal installation and coordination (Oklahoma Department of Environmental Quality 2004). As noted by Makler and Howitt, elected officials have tended to look toward Dallas, where “they perceive that that city’s air quality problem has not constrained transportation investments” (Makler and Howitt 2003). Therefore, the emission reduction strategy has focused primarily on traffic flow improvements from conventional infrastructure and some ITS, without much concern with the potential for induced travel.

Yet, even before the 8-hour ozone standard was issued, indeed since the early 1990’s, Tulsa has implemented a number of voluntary and episodic controls in order to avoid possible exceedances of ozone standards. These measures — namely RideShare and Ozone Alert! — rely to a large extent on public awareness and response. While these TCMs were considered for inclusion in the EAC, they were not included in the formal EAC submission to ODEQ and EPA, which would have made them more binding commitments. They have continued to be used as episodic ozone controls, although their success is constrained by the voluntary nature of the programs. RideShare, an area-wide carpooling program, is part of the Tulsa Commuter Choice Program managed by INCOG, and includes an online carpool matching service intended to increase occupancy levels and thus reduce overall VMT. The Ozone Alert! program is another voluntary measure that alerts individuals and business to a possible ozone exceedance for the following day. The EPA’s Office of Air and Radiation highlighted the program as a case study, noting that approximately 350 businesses have voluntarily participated in the program, taking actions that would encourage employees to limit driving on the following day through carpooling, telecommuting, flexible schedules or public transit (including free bus passes or other financial

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According to INCOG, the Ozone Alert! program was the first in its kind in the country, and has been replicated in other ozone non-attainment areas such as Dallas-Fort Worth and San Francisco (INCOG interview, 2005). Tulsa was also one of the first cities (if not the first) to use ITS, specifically freeway variable message signs operated by ODOT, to notify drivers of a pending ozone exceedence. Additional actions taken for emissions reductions include the purchase of lower emission vehicles for Tulsa Transit, and reduced fare bus rides during Ozone Alert! days, sponsored by Oklahoma Natural Gas. Probably the most effective action under the Ozone Alert! program, according to INCOG, has been the voluntary reduction of the Reid Vapor Pressure by fuel suppliers (INCOG interview, 2005). Tulsa Transit is also attempting to reduce emissions through improvements to its bus fleet. However, as noted by an INCOG planner, “in terms of getting people out of their cars and into transit, it’s not happening” (INCOG interview, 2005).

5.8.2.3 Issues

Although the EAC has been characterized as a “pro-active initiative”, the additional investment has been minimal, since most of the actions outlined in the EAC were essentially projects already completed since 1999/2000 or projects in the pipeline. For example, in the Tulsa Area Transportation Emission Reduction Strategy, which outlines the mobile source measures to be included in the SIP, 27 of the 32 capacity expansion projects listed had already been completed as of the EAC submission. This left only five capacity expansion projects outstanding, plus nine intersections still targeted for traffic signal improvements. In part, more rigorous and expensive measures, although considered and analyzed, were not included in the EAC, primarily because photochemical modeling and air quality trend analysis undertaken by EPA and independent consultants (Environ International Corporation) was showing that attainment was highly probable even in the absence of local controls.

5.8.3 ITS Deployment

As of 2002, the level of ITS deployment in the Tulsa area ranked the lowest of all metropolitan areas. This result is not highly surprising for a medium-size city with a population of approximately 800,000, slow population and employment growth and very modest traffic.

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224 The Ozone Alert! Program has been in place in 1991. See EPA case study on Tulsa’s ozone alert program: www.epa.gov/air/recipes/ozalert.html. Last accessed August 22, 2005.
225 Although ridership levels are reported by Tulsa Transit to increase on Ozone Alert! days when bus rides are free, there are doubts as to whether those increases reflect people leaving their cars and using public transit, or regular bus riders taking advantage of the free rides to make additional trips.
226 Reid Vapor Pressure (RVP) is a measure of gasoline volatility and defines its evaporation characteristics. Lowering the RVP (for example, from 9.0 psi to 7.8 psi), or volatility, can reduce evaporative emissions for VOC, and is therefore regulated by the EPA and states during the summer, when evaporative emissions are highest. See http://www.epa.gov/otaq/volatility.htm. Last accessed February 11, 2006.
228 The 2002 figures might be somewhat lower than reality, since in earlier years, it was reported that a substantial percentage of toll lanes were equipped with ETC, and that approximately 1/3 of highway-rail intersections were under electronic surveillance. These figures were reported as “No Response” and “0%” respectively for 2002.
congestion. Tulsa has only been looking seriously at ITS applications since the late 1990s, with physical deployment not beginning until 2001. In part, this recent effort has been spurred by a FHWA report that targeted Tulsa among the 25 metropolitan areas in the US with little or no ITS deployment (INCOG interview, 2005). This also lead to a brief influx of several million dollars for ITS, through federally earmarked integrated funds. Although helpful to move forward with some ITS projects, the funding was focused on integration, rather than deployment per se.

To a large extent, the ITS efforts in Tulsa are lead by the state, with federal funding coming primarily through special appropriations, such as the integration funds. City traffic engineering and public works departments in the City of Tulsa and City of Broken Arrow have largely followed the lead of ODOT, which currently owns and maintains the majority of the ITS infrastructure in Tulsa (ODOT interview, 2005). Although limited in the amount of actual ITS hardware deployed, there is relatively good interagency coordination for the ITS applications that do exist.

The principal barrier for ITS deployment has been the lack and unpredictability of funding (INCOG interview, 2005). Because of the congestion problem in Tulsa lacks any real severity, it has been difficult to justify diverting funding from conventional transportation infrastructure to ITS. Transportation and metropolitan planning agencies in Tulsa consider that the current strategy of moderate highway expansion and addressing bottlenecks in the system, coupled with slow population growth, has served to keep congestion in check. This reflects the view in Tulsa, and elsewhere, that ITS does not yet provide a true alternative to physical capacity expansion, and instead is an enhancement to physical infrastructure projects. However, they also add that as the financial costs of physical capacity expansion in highly developed urban areas (citing segments of I-44 as an example), alternatives such as ITS may become more viable (INCOG interview, 2005).

Currently, no STP funds are set aside for ITS applications, meaning that most ITS funding comes through special appropriations that the congressional delegation is able to secure. The only formula funds that are designated to ITS are a portion of state CMAQ funds, as will be discussed later.

5.8.3.1 Traffic

According to INCOG, although there is only moderate congestion in Tulsa, the congestion that does occur is largely a result of incidents and accidents (INCOG interview, 2005). Therefore, the main impetus for ITS in the Tulsa area has been both improving incident response and management, with the goal of reducing the non-recurrent congestion caused by those accidents and incidents. The organizing vision for ITS operations in Tulsa is the establishment of a Regional Transportation Management Center (RTMC). This center would operate under the supervision of a Board including ODOT, INCOG, the Oklahoma Department of Public Safety (DPS) (specifically, the Oklahoma Highway Patrol) and the City of Tulsa, and would create both institutional and real-time communications and data links between agencies responsible for traffic, emergency and transit operations (PB Farradyne 2002, p. 6). In practice, the actual deployment of this vision has been limited by the lack of funding.
To date, there is a modest number of arterial intersections under centralized or closed-loop signal control, with signal preemption at some intersections for emergency vehicles. In terms of ITS infrastructure, there are 12 CCTV cameras, approximately 34 limited-capability webcams,\textsuperscript{229} seven installed dynamic message signs (DMS) with seven additional DMS planned, and fiber optic coverage of about two-third of the highway network in Tulsa.

Somewhat independently, ITS applications have also been pursued by the Oklahoma Turnpike Authority. The Turnpike’s Electronic Toll Collection system – PIKEPASS – was deployed in 1991. The motivation for deploying ETC was not congestion, but rather the cost savings of ETC compared to manual toll booths (Public Technology Inc. 1995). The PIKEPASS tag operates with radio frequencies, and collects one-third of all tolls on the turnpike system. Although the cost saving was the primary motivation for deploying ETC, studies have shown that accidents and emissions were also reduced substantially.

5.8.3.2 Transit

Currently, there is some online transit information, although most of that information is static information on bus routes and schedules. Electronic fare payment for buses has been also implemented throughout the fixed route bus fleet, as well as automated passenger counters, and mobile data terminals, security ITS applications such as silent alarms and engine kill switches. Tulsa Transit and INCOG have both been advocating for automated vehicle location (AVL), which would enable Tulsa Transit to track buses, control headways and possibly provide real-time bus information to passenger, in order to improve the reliability and predictability of service. AVL is considered critical because the frequency of service can range from 20-90 minutes (peak period) and 30-120 minutes off peak, meaning that missing the bus often requires finding an alternative mode of travel rather than waiting for the next bus.

5.8.3.3 Information and Other

The demand for traveler information is relatively low, and adequately served by traditional channels of traffic information such as radio and television reports. The city of Tulsa has a real-time GIS-based online accident map – the principal source of congestion in Tulsa – using information from 911 calls. However, the system is often unable to map the 911 calls to the local street network, and there are no indications of direction or duration of the incident (since there is no mechanism to know when the accident is cleared).\textsuperscript{230}

5.8.4 ITS-Air Quality Links

At the same time that air quality issues were becoming a more urgent issue for transportation planners in Tulsa – with several years of exceedences threatening a possible non-attainment designation for the area – ITS was also coming to the forefront. This has led to some interesting coupling of ITS technologies and emission reduction measures, as will be discussed below.

\textsuperscript{229} These webcams do not have pan, tilt and zoom functions typical to most CCTV cameras.
\textsuperscript{230} See link to “traffic accidents” at maps.cityoftulsa.org/. Last accessed March 20, 2006.
5.8.4.1 Projects

Although Tulsa’s ITS experience is relatively recent, there are a few projects that leverage ITS in order to improve air quality. For example, the online carpool matching service that supports Tulsa’s Rideshare program represents one ITS element deployed within the context of air quality. Rideshare uses RidePro software to match potential carpool candidates by home and work addresses, schedule preferences and flexibility, and can also be specific to employer. Tulsa also has been able to coordinate ITS and the Ozone Alert! program by displaying information on Ozone Alert! days on ODOT’s dynamic message signs. This requires substantial interagency coordination in that the Tulsa Branch of ODEQ will forecast next day ozone levels and call the alerts (by 3:00 pm), while the Air Quality Committee of INCOG implements the Ozone Alert! system, notifying corporations and the public, ODOT puts messages on the VMS to notify drivers of pending Ozone Alerts, and remind them “to consider other commuting options.”

Table 5-20 ITS content of air quality programs/projects in Tulsa

<table>
<thead>
<tr>
<th>Measure</th>
<th>Type</th>
<th>Objective</th>
<th>ITS Content</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Reduce VMT via carpooling, walking/biking, transit, or telecommuting.</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Public awareness on good driving habits – reduce idling, chain trips.</td>
<td></td>
</tr>
<tr>
<td>Arterial Signalization&lt;sup&gt;232&lt;/sup&gt;</td>
<td>TSM</td>
<td>Reduce idling times at intersections.</td>
<td>Signal optimization.</td>
</tr>
<tr>
<td>Rideshare</td>
<td>TDM</td>
<td>Reduce VMT via carpooling.</td>
<td>Web-based carpool matching.</td>
</tr>
</tbody>
</table>

The inclusion of several signal improvement projects in Tulsa’s EAC reflects the position of local transportation planners that the perception of the relationship between ITS and air quality has shifted over the years. According to planners at INCOG, when ITS was still a relatively young concept, the air quality benefits were tied to ITS as an attempt to “sell” these projects to local decisionmakers. However, ITS matured into a more viable program on its own. As a result, the air quality benefits were quantified not to “sell” ITS projects, but rather to delay a possible ozone non-attainment designation. In the development of the EAC, INCOG included and quantified several signalization projects that were already in the pipeline and that could show emissions reductions. In fact, twelve of the projects – about one-quarter of all projects – listed in the Transportation Emissions Reduction Strategy for the EAC were traffic signal installations, upgrades or modifications.

Variable speed limits on interstates was another option considered for reducing emissions and avoiding possible ozone exceedances (ODEQ interview, 2005). However, the projected costs involved in implementing the system, concerns about a negative reaction by the public, and the

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<sup>232</sup> This measure was the only one to be included in the Early Action Compact for Tulsa and the SIP for the State of Oklahoma.
burdens of additional studies and approvals required by the state DOT to change speed limits, deterred proponents from further pursuing the concept.

5.8.4.2 Funding

Although there are currently no non-attainment areas in Oklahoma, the state does receive the minimum apportionment of federal CMAQ funds available to all states regardless of whether they have non-attainment areas or not. Non-attainment states can use the CMAQ funds as they would use STP funds, with no emission reduction reporting requirement. Tulsa and Oklahoma City have reached an agreement with ODOT to funnel a portion of those CMAQ funds to their MPOs ($1 million of the $8 million state CMAQ funds, with $500,000 given to each MPO). In the case of Tulsa, about $200,000 of those funds are set aside to transit, while the remainder is used for ITS and transportation enhancements such as bicycle trails. According to INCOG, a portion of Tulsa’s annual CMAQ funding will be directed to the City of Tulsa in order to support their signal coordination efforts. The rest of the $7 million in CMAQ funds received by ODOT are used as normal STP funds, which is allowed for states without non-attainment areas, meaning greater flexibility in the use of these funds and no requirement to report emissions reductions to the FHWA.

There has been some debate over CMAQ funds and their use. With the possibility of a pending non-attainment designation with 8-hour ozone, the question was whether it was preferable to have a non-attainment designation, and the additional CMAQ funding that would come with that, or to remain in attainment, with only minimal CMAQ monies. However, at least for INCOG, the regulatory burden that comes with non-attainment is not perceived to be worth the additional CMAQ dollars that could be used to fund ITS. In other words, according to INCOG, “we prefer to have non-attainment, and stumble along [without the funding]” (INCOG interview, 2005).

5.8.4.3 Evaluation

For the Tulsa EAC, future on-road mobile source emissions were estimated using EPA’s MOBILE6 model, using data on system-wide vehicle miles traveled (VMT) and average network speed derived from a regional transportation demand model. The EAC contained two types of emissions reduction strategies: capacity improvement projects and intersection improvement projects (which included the ITS component). For the first strategy, the expansion projects were modeled in the regional transportation model to look at changes in VMT and network speeds from increase capacity through certain bottlenecks. However, given the micro-scale of ITS and signal improvements, the intersection improvements, such as traffic signal improvements, were calculated making off-model, link-based assumptions (meaning that it was not included in a network model). The base case for 2007 compared to the control strategies included in the EAC are shown in Table 5-21.
Table 5-21 Transportation emission reduction strategies for the Tulsa EAC

<table>
<thead>
<tr>
<th></th>
<th>On-road Mobile Emissions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NOx weekday (tons per day)</td>
</tr>
<tr>
<td></td>
<td>Base Case 2007</td>
</tr>
<tr>
<td></td>
<td>Control Strategy 2007</td>
</tr>
<tr>
<td></td>
<td>Difference</td>
</tr>
<tr>
<td></td>
<td>Percentage</td>
</tr>
<tr>
<td></td>
<td>VOC weekday (tons per day)</td>
</tr>
<tr>
<td></td>
<td>Base Case 2007</td>
</tr>
<tr>
<td></td>
<td>Control Strategy 2007</td>
</tr>
<tr>
<td></td>
<td>Difference</td>
</tr>
<tr>
<td></td>
<td>Percentage</td>
</tr>
</tbody>
</table>

Source: Appendix A of Memorandum of Agreement between INCOG and ODEQ. Cited in (Oklahoma Department of Environmental Quality 2004)

Yet, because only the aggregate emissions reductions are included in the December 2004 SIP, one cannot ascertain the relative contribution of intersection improvements and ITS compared to traditional expansion projects, or review the methods used to calculate those reductions. Furthermore, while the NOx reductions reported are relatively important, with 5% of total mobile sources, the VOC reductions of 0.05% are minimal, and probably fall well within the level of uncertainty of forecasting total mobile source emissions.

Although pollution was not a factor in deploying the PIKEPASS on the Oklahoma Turnpike system, early studies showed that emissions at toll plazas with ETC may have been substantially reduced compared to manual toll collection. The Clean Air Action Corporation conducted measurements of emissions changes from use of the PIKEPASS compared to manual toll collection using dynamometer testing and observations of toll plaza operations and traffic flows (MITRE Corporation 1996, p 14). The study was carried out as part of a demonstration by Northeast States for Coordinated Air Use Management (NESCAUM) to developed protocols and procedures that could be used in a trading program of emissions reductions credits. Measurements were taken at the Muskogee Turnpike in Oklahoma, using the ETC experience gained there since 1991, in order to assess the potential for reductions of a similar PIKEPASS program if fully implemented in both Massachusetts and New Jersey (Northeast State for Coordinated Air Use Management 1993; Roberts and Shank 1995). Table 5-22 compares emissions rates (g/mi) based on individual transactions, considering a manual toll gate, a limited pass, and a full pass (requiring no slowing down).

Table 5-22 Emissions rates (g/mi) for three speed profiles

<table>
<thead>
<tr>
<th></th>
<th>Toll Gate</th>
<th>Limited Pass</th>
<th>Full Pass</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>65-0-65 mph</td>
<td>65-30-65 mph</td>
<td>60 mph even</td>
</tr>
<tr>
<td>HC</td>
<td>1.2</td>
<td>1.0</td>
<td>0.2</td>
</tr>
<tr>
<td>NOx</td>
<td>1.1</td>
<td>0.9</td>
<td>0.6</td>
</tr>
<tr>
<td>CO</td>
<td>30.6</td>
<td>20.0</td>
<td>8.5</td>
</tr>
</tbody>
</table>

Source: (Roberts and Shank 1995, Table 2-2)
5.8.5 Summary

As an attainment area since the 1990 CAAA, Tulsa has not seen its investment in transportation projects challenged or restricted on the grounds of possible air quality impacts. On the contrary, as evidenced by the Transportation Emission Reduction Strategy, Tulsa has been able to pursue a strategy of moderate capacity expansion to deal with its mild congestion, with many expansion projects showing air quality benefits through speed improvements. ITS deployment levels have been low, indeed, among the lowest in the nation. However, even with the relatively few ITS applications that have been implemented in the Tulsa area, with the threat of a possible non-attainment designation for ozone, Tulsa has been able to use ITS to its advantage to develop a EAC “safeguard” against non-attainment. Given the small size of the city and the more limited number of agencies and staff involved in ITS and air quality, Tulsa has also been able to experiment with ITS as a tool for air quality management. These small-scale but important innovations, such as Ozone Alert! notifications on VMS, focus only on possible ozone exceedances, which is appropriate, given that Tulsa’s ozone problem is one of sporadic, high ozone levels. Finally, evaluation of ITS’ air quality impacts has been limited, and judgment regarding the air quality impacts of ITS tends to be based more on the principal that improving bottlenecks and other congestion points will reducing idling and thus emissions, than on detailed modeling or measurement. Indeed, one of the few in-depth studies of emissions impacts of an ITS application, the NESCAUM study, was intended for application in the Northeastern U.S., not for local use.
5.9 CONCLUSIONS

In this chapter, we have explored five very different cases of cities with varying levels of air quality problems and ITS deployment, and have seen that each city has a unique history in terms of its experience with air quality management and ITS deployment, both of which have shaped the linkages (or lack thereof) between ITS and air quality. One of the core issues, is to what extent these metropolitan areas have consciously leveraged the connections between air quality and ITS. Another issue relates to the motivations for making those connections, whether to (1) further justify already planned ITS deployments, (2) make improvements to air quality at the margin through ITS while continuing to pursue an aggressive automobile-oriented mobility agenda, or (3) actively experiment with ITS as a tool to reduce emissions and improve air quality.

Houston stands out as the metropolitan area with the most extensive experience in using ITS to reduce emissions, in particular through traffic flow improvements. Houston also has a well-documented and consistent methodology for assessing those impacts, albeit one that leaves aside the important question of induced travel. Los Angeles, with moderate levels of ITS deployment and an “extreme” air quality problem, has seen some attempts to use its traffic-related ITS deployments for air quality purposes frustrated. However, it has been more successful in using ITS as a tool in its traditional transportation demand management strategies. Orlando, with high levels of deployment and an early and successful start with ITS, in the absence of major air quality problems, has not used ITS for air quality purposes, although some agencies have used independent evaluations of the emissions impacts of their ITS deployment in some instances to bolster public perception of their environmental record. Finally, Tulsa, Oklahoma, with some of the lowest levels of ITS in the nation, and near free-flow conditions on its transportation network, came close to falling into non-attainment with the promulgation of the 8-hour ozone standard. As a result, despite its low levels of ITS technology deployment, Tulsa has used ITS in interesting ways to safeguard itself against a non-attainment designation.

Having described each city and its air quality and ITS story, in the next chapter, we will revisit the concepts and theories outlined in Chapter 5, to see how they can explain what has occurred in each city, in terms of (1) innovation with ITS, (2) cooperation and overcoming the fragmentation between air quality, transportation and metropolitan planning agencies, (3) and the ability to assess new technologies and their environmental impacts. Bringing these factors together, we will identify the factors that determine to what extent cities are able to experiment with the deployment of new technologies in such a way that address both their performance and environmental impacts.
CHAPTER 6. ANALYSIS OF U.S. CASES USING IIDAPT FRAMEWORK
6.1 INTRODUCTION

In this chapter, we will apply the theoretical framework to the case study cities, in order to assess to what extent the conditions in each city accurately predict the actual outcomes observed for Integrated Innovation, Deployment and Adaptation of Public Technologies (IIDAPT). While we have described how to measure and describe actual IIDAPT outcomes in ITS innovation for air quality in Chapter 4, we still need to develop a set of concrete, albeit largely qualitative, measures for the conditions that determine IIDAPT outcomes. Therefore, we will first review the seven conditions for IIDAPT.

In Section 6.2, we will then review the IIDAPT levels predicted by those conditions for each city, and compare the predicted and actual IIDAPT levels. This constitutes the testing of our theoretical framework. However, because this research has an important theory building component, we will also review how the cases point to possible adjustments and refinements to the theoretical framework. Therefore, in addition to the predictive ability of the IIDAPT framework, we will also look at some of its additional explanatory capabilities in Section 6.3. Particularly, we will look at more closely at this issue of mutual benefits in the deployment of technologies that, on the surface, should be “win-win” outcomes for the agencies involved.

In Section 6.4, we will review the policy implications of the theoretical framework we have developed for IIDAPT. First, we review how the IIDAPT framework can be used both to assess the possibilities for IIDAPT and to identify “changeable” conditions in order to improve the chances for successful IIDAPT. Second, we will assess how these five cities have deployed ITS for air quality objectives, and identify innovative uses of ITS for air quality, taking a best practices approach from the technology perspective. In this section, we will also answer the questions of whether we are “doing a good job” in deploying ITS in a way that supports air quality goals. Finally, we will look at the implications that this may have for transportation conformity and the CMAQ program, as the two key mechanisms for linking transportation investment decisions to air quality.

6.1.1 Seven Conditions

First, we will describe more concretely the seven conditions for the case of ITS and air quality. Some of these conditions can be described with quantitative measures, while others will be more qualitative in nature. The seven IIDAPT conditions are drawn from the propositions presented in Chapter 4. We now specify how to measure and/or describe each of the conditions below.

6.1.1.1 Problem Severity

One of the key drivers of innovation by public sector agencies is an existing problem or need. We postulate that organizations will innovate when their current standard operating procedures and tasks prove to be inadequate due to changes in the external environment. As the mismatch grows between the problem or need that must be addressed by a public sector agency and that agency’s performance in addressing that problem or need, there will be, in theory, both internal and external pressures to innovate.
The five case cities were chosen based in part on a standard indicator of problem severity for air quality — their designation for air quality attainment/non-attainment for the 1-hour ozone standard. At the low end of the spectrum, are cities in attainment with the ozone standard, with increasing problem severity ranging from marginal, moderate, severe-15, severe-17, to extreme. \(^{233}\) The hypothesis is that in cities facing more challenging air quality problems, public sector agencies will face more pressure internally, from other agencies in the metropolitan area, from the federal government, and from external stakeholders, including the general public, to innovate in order to address those problems.

Another problem area is congestion. Although cases were not chosen based on congestion levels, the cases do show a wide variation in levels of congestion, ranging from the most congested city in the US, Los Angeles, to Tulsa, with mild congestion. Indeed, as seen in Chapter 5, there is some correlation between congestion and severity of the air quality problem. For a city facing both congestion and air quality problems, we suggest that ITS solutions would be sought as a tool to address both issues simultaneously and in a cost-effective manner. The key indicator used for congestion levels is the travel time index developed and measured annually by the Texas Transportation Institute in their Urban Mobility Report. \(^{234}\) This indicator is highly useful because it applies a consistent methodology to all large metropolitan areas in the US, and is updated almost every year. It also influences decisionmakers' perception of the severity of the problem, since it is widely cited by transportation professionals as a measure of their own performance on dealing with congestion. \(^{235}\) However, because we are interested in the use of ITS for emission reductions, the primarily problem area we are concerned about is air quality.

6.1.1.2 Internal Resources

While there may be a strong need to innovate in response to the problems facing agencies, the extent to which innovation can and will occur also depends upon their capacity to innovate. That capacity depends, in turn, on the level of resources available to an agency in terms of funding, staff size, and the training and professional background of personnel. There are two aspects to this question of internal resources for ITS and air quality. First, is whether there are transportation agencies in the region with the funding, staff and expertise needed to effectively deploy and operate ITS technologies. The second level, of interest here, is whether the agencies in the region have the capacity to analyze, model, measure and/or demonstrate the possible air quality benefits of ITS, and deploy ITS technologies in a way that link them to air quality management efforts.

\(^{233}\) The category of severe is divided into two parts based on the number of years they were given to bring their areas back into attainment of the national ambient air quality standards (15 years or 17 years).

\(^{234}\) The travel time index represents the ratio of travel time during peak congestion, to the travel time during free flow conditions. No congestion would mean a travel time index of 1. If a trip during peak congestion takes 50% longer than the same trip under free flow conditions, the travel time index would be 1.5.

\(^{235}\) For example, in long-range regional transportation plans, metropolitan areas often look at long-term trends in their own travel time index, as well as comparisons with other cities of similar size.
In general, we would predict that the larger agencies, in terms of staffing—engineers, analysts, planners, etc.—would be better equipped to deploy ITS and to experiment with ITS as a tool for emissions reductions, as well as carry out assessment of those innovations. This cuts two ways. First, within the same metropolitan area, we would anticipate that bigger agencies with more resources, such as a state DOT or a major transit agency, would be more innovative than smaller agencies, such as city or county transportation departments. Second, it has implications for comparisons between different metropolitan areas in terms of the relative size, staffing and funding of their transportation agencies.

However, we are interested not simply in innovation with ITS, but particularly in the use of those technologies for air quality improvements. As an indicator of the internal resources for integrated innovation in ITS and air quality, we will look specifically at the staff size of the Metropolitan Planning Organization (MPO). The MPO is typically responsible for the list of Transportation Control Measures for the State Implementation Plan (SIP), allocates federal funding from the Congestion Mitigation and Air Quality (CMAQ) program, and, in many cases, serves as the lead agency in developing a regional ITS architecture and strategic plan. The MPO will be the key agency in facilitating the use of ITS as an emission reduction measure, either through funding or through incorporation in the air quality planning documents. We will therefore look both at total MPO staff size, and more specifically, the number of staff members involved in transportation and air quality planning (although the purpose is to gain a sense of the capacity of the MPOs, not the exact number of staff).

6.1.1.3 Dedicated Resources

According to Nohria and Gulati, “innovation and slack are concepts at the very core of organization theory” (Nohria and Gulati 1996, p 1245). In the realm of public sector innovation, Walker used the concept of “slack” to describe the “free-floating” resources such as money or skilled staff, that may be available to experiment with new innovations (Walker 1969). For ITS innovation, there could be two forms of slack resources. The first set of resources are the CMAQ program funds, which come with specific mandates from the federal government on their use, explicitly excluding the use of this funding on highway expansion projects that would favor the use of single occupancy vehicles (SOVs). The other possible sources of slack resources are those funds that are allocated specifically to the area of ITS. Even though, in theory, they could be used for more traditional transportation projects and enhancements, they are set aside by the agencies for specific categories of projects such as ITS. Examples of these are revenues generated through local sales tax, and with a certain percentage allocated to operations projects such as ITS, or Surface Transportation Program (STP) funds, a portion of which may similarly be set aside for ITS. In principal, once allocated, these funds can act in the same manner, as dedicated funding sources for ITS and other operations activities, and thus lead to a higher level of innovation. However, the primary indicator for dedicated resources for air quality-improving ITS projects will be the average annual CMAQ funding to a metropolitan area.

236 An competing hypothesis could suggest that smaller agencies, which are less bureaucratic and more “nimble,” could be better innovators. However, we would also suggest that even smaller agencies would need sufficient internal resources in terms of the quality and training, if not the number, of staff.
The CMAQ program itself was innovative in providing dedicated funding, for the first time, for transportation projects that were specifically intended to improve air quality in non-attainment areas. The characterization of CMAQ funds as "slack" resources for innovative transportation and air quality projects seems to be borne out by how they are used by the states. The Surface Transportation Policy Program (STPP) published a newsletter in 2003 highlighting the pattern of chronic "under-spending" of CMAQ funds. According to their analysis, only 81% of the total CMAQ funds apportioned to the states was actually spent, compared to 94% for the National Highway System (NHS) program funding category (Surface Transportation Policy Program (STPP) 2003). Therefore, it seems that while states spend nearly all funding available for traditional highway programs, they have a harder time "spending" (or obligating) CMAQ funds for more innovative projects, despite the condition that these funds are lost if not spent within a certain time period, with limits on carryover of CMAQ funds. Indeed, according to the STPP, "six states with non-attainment metro areas and poor spending records on CMAQ have nevertheless obligated more than 100 percent of available NHS funds" (Surface Transportation Policy Program (STPP) 2003).

6.1.1.4 Cost

Dedicated resources indicate the extent to which there is slack funding available to undertake innovations. Without dedicated resources, there would be a more competitive funding environment, and allocating funding for experimentation with new technologies and innovative strategies would be substantially more difficult. However, the other side of the coin is the relative cost of innovations. With lower cost innovations, the consequences of failed experiments are quite not as severe, whereas more expensive failures draw innovation into the light of the public eye, raising issues of accountability and questions regarding whether public sector agencies should, in fact, attempt to be more innovative. 237

ITS projects are generally orders of magnitude less expensive, compared to capital infrastructure projects for freeway, arterial or transit systems. As a condition for IIDAPT for our case study cities, however, it is difficult to define a measure for the relative cost of ITS projects, since it depends on the cost of the "alternative" projects. It would require a comprehensive assessment of the relative cost-effectiveness of ITS projects compared to alternative projects for both congestion mitigation and air quality improvements, and how that differs from one metropolitan area to another, or even on a project-by-project basis. Although this is an interesting research question, it is beyond the scope of this thesis. Therefore, we will look at the relative cost of ITS according to the perceptions by transportation agencies of the financial barriers to conventional infrastructure improvements. This suggests that in metropolitan areas where the financial costs of physical capacity expansion projects are almost prohibitively high, ITS will become an increasingly attractive option.


6.1.1.5 Mutual Benefits

Of all of the conditions discussed here, "mutual benefits" is the most difficult to define, not to mention measure, in the same manner that we can identify, for example, a measure of problem severity, dedicated resources or internal resources. For the moment, we will measure mutual benefits somewhat dichotomously – as the requirement for a non-attainment metropolitan area to meet the requirements for transportation conformity with air quality plans. If an area must meet the transportation conformity requirements, and identify and adopt local transportation control measures (TCMs) to reduce emissions from mobile sources, then there are benefits to the air quality agencies of using ITS as an available TCM. There are also benefits to the transportation agencies deploying ITS, as they can point to air quality benefits of their technologies, and perhaps more importantly, gain access to additional funding from the CMAQ program. A non-attainment designation would indicate that there are also mutual benefits to the transportation organizations in supporting conformity demonstrations by implementing TCMs, and therefore helping the region avoid the possible delays in federal transportation funding that can result from conformity problems.

We will use as an indicator of mutual benefits simply whether the area is attainment or non-attainment, even through this creates some overlap with the condition of problem severity. Indeed, as illustrated in Figure 6-1, problem severity can lead directly to innovation, or can lead to cooperation by creating dedicated resources (CMAQ funds) that are a source of mutual benefits. Therefore, while there is overlap in our definitions of problem severity and mutual benefits, because the dynamics of these process are different, the case study approach allows us to disentangle those effects.

6.1.1.6 Number of Organizations

The size of the organizations as a factor in innovation was considered above, suggesting that the larger agencies are more likely to innovate. However, innovation in ITS often requires the involvement of numerous agencies. Innovation in ITS, with the additional purpose of reducing mobile source emissions, means that there will be involvement from more agencies, such as the MPO staff, and the air quality agencies. Therefore, in addition to the size of individual agencies, another important factor is the number of agencies involved and the overlap and competition between their functions. We hypothesize that a higher number of agencies actively involved both in local air quality management and ITS deployment in a metropolitan area will make coordinated deployment and innovation more difficult. Again, this does not necessarily have to be a number (of organizations); it could be general description of the key players that are involved in these two areas.

6.1.1.7 New Information

Finally, for each metropolitan area, we will look at the abundance and general quality of the studies that are undertaken to assess the air quality impacts of ITS. One difficulty is that many internal evaluations or consultant's studies are not published or easily accessible. We will use as a guide those studies that appear on the Joint Program Office's ITS benefits and costs database,
studies published in journals, working papers and reports for universities, research institutes, and government agencies, and other non-published studies and evaluations. Some of these studies were reviewed in Chapter 2, and we use the discussion from that chapter to assess the quality of and possible problems with these studies. We will also consider the extent to which agencies have partnerships or other relationships with research institutions and universities for studies and assessments of actual deployments. One of the largest sources of information, will be the studies done for purposes of CMAQ evaluation and funding eligibility. But, as mentioned elsewhere, the background information regarding how emissions reductions were calculated is often quite difficult to access.

Now that we have discussed how to measure the conditions for IIDAPT, Table 6-1 lists the seven IIDAPT conditions, and summarizes how those conditions will be described for the case of ITS and air quality. To be clear, while the general IIDAPT conditions, shown in the left column, could be used for other technologies and policy/issue areas, the measures and descriptions employed here are specific to the issue of ITS and air quality.

Table 6-1 Seven Conditions for IIDAPT

<table>
<thead>
<tr>
<th>IIDAPT Condition</th>
<th>Measure/Description for ITS and air quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Problem severity</td>
<td>1-hour ozone designation (ex: attainment, serious, severe, extreme)</td>
</tr>
<tr>
<td></td>
<td>Congestion levels (travel time index)</td>
</tr>
<tr>
<td>Internal resources</td>
<td>Staff size of MPO (total staff, transportation/air quality staff)</td>
</tr>
<tr>
<td></td>
<td>Size of city/county transportation agencies, air quality agencies</td>
</tr>
<tr>
<td>Dedicated resources</td>
<td>Amount of average annual CMAQ funding</td>
</tr>
<tr>
<td>Cost</td>
<td>Perceptions of ITS as an “affordable” measure</td>
</tr>
<tr>
<td></td>
<td>Perceptions of financial barriers to conventional infrastructure improvements</td>
</tr>
<tr>
<td>Mutual benefits</td>
<td>Requirement to meet transportation conformity requirements</td>
</tr>
<tr>
<td>Number of organizations</td>
<td>Number of organizations actively involved in air quality management and ITS deployment in metropolitan area</td>
</tr>
<tr>
<td>New information</td>
<td>Number and “quality” of studies assessing the air quality impacts of ITS</td>
</tr>
<tr>
<td></td>
<td>Partnerships with research universities/institutions</td>
</tr>
</tbody>
</table>

6.1.2 Local Context

These seven conditions capture some of the more important factors that, according to our theory, are important determinants of how much each city employs ITS with the objective of improving air quality as well as mobility. These conditions will affect the four activities that are part of IIDAPT: cooperation, innovation, assessment and adaptation (see Figure 6-1). To avoid losing sight of the larger picture and to take into consideration the broader political and institutional environment in which all transportation and air quality decisions are made, we will also refer to the “local context” for each city. This “context” incorporates the history of air quality and transportation decisionmaking and major investments in each city during the emergence of ITS and after the passage of the 1991 ITSEA and the 1990 CAAA, which were important milestones in establishing the CMAQ program and strengthening the transportation conformity requirements. Local context also captures some of the critical events, issues and policy directions that have defined the transportation and air quality agendas in each metropolitan area.
We suggest that based upon these seven conditions (derived from the theories presented in Chapter 4) we can generally predict IIDAPT levels. Nevertheless, there cannot be a full explanation and understanding of the dynamics that influence IIDAPT without a firm basis in the unique circumstances and history of each city. For this reason, we chose the case study format, and described these contextual issues in depth in Chapter 5. As will be seen at the end of this current chapter, these issues of local context are important in explaining, if not predicting, what are perceived to be mutual benefits or not. It will help us to further explain both the levels of IIDAPT, and the unique patterns of IIDAPT in each city.

We will now return to the cases themselves, using the measures for both IIDAPT conditions and outcomes, to evaluate how well the theoretical framework performs in predicting IIDAPT levels for the five cities.
6.2 ANALYSIS OF CASES

Boston, Houston, Los Angeles, Orlando and Tulsa were chosen from a list of over 70 metropolitan areas, according to their air quality problems and their levels of ITS deployment. These five metropolitan areas differ substantially in not only the magnitude, but the nature of their air quality problems – sources, geography and meteorology, local emissions and transported pollution – as well as in the modal mix and level of ITS deployment. Because our measure of Integrated Innovation, Deployment and Adaptation of Public Technologies (IIDAPT) could only be determined after the case study work, the cases clearly could not have been chosen in advance according to IIDAPT levels. These five cases appear to have also captured a range of levels for IIDAPT in using ITS technologies for air quality improvements from on-road mobile sources, according to our definition of the core and supporting activities for IIDAPT, as shown in Table 6-2. This table was developed, along with a numerical scale in Chapter 4.

Table 6-2 Qualitative Scale for IIDAPT

<table>
<thead>
<tr>
<th>Cooperation</th>
<th>Innovation</th>
<th>Assessment</th>
<th>Adaptation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>High</strong></td>
<td>More than one agency actively engaged in the design, deployment and/or operation.</td>
<td>High level of novelty in the technology or its adaptation to multiple policy goals.</td>
<td>Rigorous ex-ante and ex-post evaluation.</td>
</tr>
<tr>
<td><strong>Low</strong></td>
<td>More than one agency indirectly involved or playing a supporting role in the design, deployment and/or operation.</td>
<td>Some novelty in the technology or its adaptation to multiple policy goals.</td>
<td>Some ex-ante or ex-post evaluation only.</td>
</tr>
<tr>
<td><strong>None</strong></td>
<td>No cooperation.</td>
<td>No innovation.</td>
<td>No evaluation.</td>
</tr>
</tbody>
</table>

However, before actually comparing actual IIDAPT for the five cities, we must first more rigorously measure IIDAPT outcomes for each of the cities. As described in Chapter 4, this involves assessing each ITS application that could be defined as IIDAPT, screening out those that are and are not IIDAPT according to Table 6-2, then numerically scoring those technologies that are IIDAPT on a scale of 0-6. Ideally, this process is done for all IIDAPT in each city. However, for some of the larger case cities, where there are possibly tens of similar IIDAPT within the same ITS category, we will score according to a representative IIDAPT for each category.

The next step is then to scale up from the individual technology to the metropolitan level, using two measures, one for the average level and range of IIDAPT (how close individual technologies are to the highest IIDAPT levels and how many ITS categories have at least one example of IIDAPT), and the intensity of IIDAPT, or the use of ITS for air quality improvements
compared to other transportation-based measures to improve air quality. These are summarized in three quantitative measures for the metropolitan level, again, as described in Chapter 4. In order to compare across cases, we then take the product of the average level, range and intensity of IIDAPT, to develop a summary measure, as shown in Table 6-3 below.

Table 6-3 Measures of IIDAPT at the metropolitan level

<table>
<thead>
<tr>
<th>IIDAPT measures</th>
<th>Houston</th>
<th>Los Angeles</th>
<th>Metropolitan Area</th>
<th>Orlando</th>
<th>Tulsa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Level (AL)</td>
<td>0-6</td>
<td>0-6</td>
<td>0-6</td>
<td>0-6</td>
<td>0-6</td>
</tr>
<tr>
<td>Range (R)</td>
<td>0-10</td>
<td>0-10</td>
<td>0-10</td>
<td>0-10</td>
<td>0-10</td>
</tr>
<tr>
<td>Intensity (I)</td>
<td>0-100%</td>
<td>0-100%</td>
<td>0-100%</td>
<td>0-100%</td>
<td>0-100%</td>
</tr>
</tbody>
</table>

While we stress the process for obtaining the quantitative measures, they are only supporting measures to what is primarily a qualitative description of IIDAPT. However, this process is deliberately emphasized here in order to begin to set the stage for future research, which could use more survey-based methods in which a larger sample IIDAPTs would be coded and scored for statistical analysis.238

Therefore, actual IIDAPT outcomes are measured in terms of the average level, range and intensity of innovation with ITS for air quality purposes. The ideal IIDAPT for ITS and air quality involves innovation and experimentation with ITS technologies in order to exploit possibilities for air quality as well as mobility improvements, along with rigorous analysis and documentation of emissions impacts of ITS. Nonetheless, it should be emphasized that this does not necessarily reflect actual emissions reductions or air quality outcomes. A more cynical interpretation is that areas are simply playing the “numbers game” for conformity, for example, manipulating the numbers to show emission reductions from ITS projects used as TCMs. Or, they may be juggling different funding pools, such as CMAQ, and end up funding projects that may be eligible for air quality benefits, although not necessarily appropriate from the air quality standpoint.

The extent to which these are indeed real emission reductions or simply manipulation of the numbers to “show” air quality benefits, cannot be determined for all of the cases. In part, the problem lies in discerning the actors’ intentions from their actions. Do actors try to “game” the system by “sneaking in” ITS projects with questionable air quality benefits into the CMAQ program or air quality programs? Do they use and even distort information on air quality benefits to support their ITS efforts, or enhance their organizational image? Or, do these organizations truly believe that ITS is a low cost, viable option for providing both congestion relief to travelers, while reducing emissions from smoother traffic flows? Indeed, because many questions regarding the air quality impacts of ITS have not been fully resolved in the research,

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238 In a study by Borins, for example, a relatively large sample (217) of local and state government innovations (semifinalists in the Ford Foundation-Kennedy School of Government’s State and Local innovation awards program), were coded for statistical analysis. For the summary of the methodology, see pages 12-18 in Borins, S. (1998). Innovating with Integrity: How Local Heroes are Transforming American Government. Washington, DC, Georgetown University Press.
we cannot expect it to be resolved in the minds of the decisionmakers, who may also have professional and personal preferences and organizational biases for how the uncertainty is resolved.

Resolving this question of true intent would also require recreating many of the assessments of the emissions impacts of these technologies. In Chapters 2 and 3, we highlighted some of the key uncertainties, and attempted to differentiate between more and less rigorous analyses, and illustrate how analyses can be misleading. We have also discussed some of the accepted methodologies for assessing the air quality impacts of ITS — where available. However, even finding problematic assessments may not constitute evidence of “gaming” but rather a lack of resources, time or interest in undertaking “good” assessments.

We will now review the cases, to evaluate the seven conditions, the levels of IIDAPT that they would predict, and compare that to actual IIDAPT outcomes. While the seven conditions will be the primary focus, the case study approach also allows us to explore other possible explanatory variables and interactions between the conditions. Therefore, where case study site visits, interviews, and review of plans, projects, and analyses indicate that other factors were important in influencing or enabling IIDAPT, we will describe those factors as well.
6.2.1 Houston

We begin our analysis with the case of Houston for several reasons. First, Houston has some of the highest levels of deployment of ITS in the nation, and has been innovative on the institutional side through the formation and evolution of TranStar. In addition, the area has also experienced some of the worst air pollution in the US, at times rivaling Los Angeles,\(^{239}\) and has faced challenges dealing with congestion in the face of rapid growth and expansion of its population, economy and urban area during the 1990s.

In terms of what to expect for the use of ITS to also promote air quality objectives, early indications in Houston pointed toward high levels of IIDAPT. Specifically, soon after TranStar was established, the following description of Houston’s ITS program was included in a brochure entitled *Traveling with Success: How Local Governments Use Intelligent Transportation Systems*, published by Public Technology, Inc.:

"As one of the nation’s major travel corridors, the thriving city of Houston and surrounding Harris County have recognized and accepted the fact that cost and environmental concerns now restrict physical improvements to existing transportation infrastructure. To meet congestion and pollution challenges, the city of Houston, Harris County, the area’s Metropolitan Transit Authority, and the Texas Department of Transportation have joined forces to establish the Houston Intelligent Transportation System..... One major prong of Houston’s intelligent transportation effort will encourage commuters to use mass transit instead of the costly one-person-one-car approach so ingrained in American culture" (Public Technology Inc. 1995, p 52).

This statement was part of a FHWA-funded report on how local governments were using, or planning to use ITS in the early years of the ITS program.\(^{240}\) Indeed, this seems to embody the concept of IIDAPT – in terms of cooperation, innovation, and, above all, the integration of congestion and pollution mitigation objectives. It is also interesting in that its suggests technology can be used as a catalyst for deeper social changes in how people travel. Yet, as we will see later in this section, although IIDAPT has indeed been high in Houston, the form of actual deployment has differed substantially from the above description. In particular, the balance in the use of ITS has come out in favor of improvements of traffic conditions on freeways and arterials, despite the earlier indications that ITS technologies and information might be used as a means to make more fundamental changes in travel behavior in Houston.

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\(^{240}\) At the time of the writing of this report by Public Technology, Inc. (PTI), Douglas W. Wiersig was the Executive Director of TranStar, and also chaired PTI’s Urban Consortium Transportation Task Force which developed this report.
Air quality in Houston, designated a severe non-attainment area, has improved somewhat over the last 10-15 years, although with nowhere near the rate of improvement that has been seen in Los Angeles.\textsuperscript{241} In fact, ozone concentrations and the number of days exceeding the ozone standards in Houston are often higher than in Los Angeles. Moreover, as suggested in Chapter 5, there are indications that Houston's current air quality strategies are not going to be enough to bring the area into attainment. In terms of congestion, Houston also has a significant problem, ranking sixth in congestion levels according to TTI's Urban Mobility Report. With population growth continuing to be strong, congestion seems likely to persist, if not worsen.

For a measure of Houston's internal resources, we look at the size of the MPO staff, and the number of staff dedicated to transportation and air quality issues. With a total staff of over 200, there are also nearly 60 planners, analysts and program managers and coordinators for transportation and air quality. In an open-ended interview protocol,\textsuperscript{242} interviewees in Houston referred to the MPO as an important resource for the region, in terms of both its size as well the training and education of its staff. For example, an interviewee from TranStar suggested that having analysts with doctoral degrees was an important factor in Houston's ability to utilize CMAQ funds for ITS projects, because of their ability to assess and demonstrate air quality benefits from ITS deployments (TranStar interview, 2005).

Houston receives substantial CMAQ funding, an important dedicated resource for experimentation with ITS for air quality purposes. At the national level, the state of Texas ranks third in the amount of annual CMAQ program federal funding, after California and New York. Houston, with the worst air quality in Texas and the city with the largest population in the state, receives the largest share of the Texas' total CMAQ funding.

Mutual benefits between transportation agencies, air quality agencies, and the metropolitan planning organization also appear to be high, given the need to meet conformity requirements and bring the area into attainment with air quality standards by 2010.\textsuperscript{243} Houston also has a large base of ITS deployments, creating possibilities for experimentation and adaptation of those deployments for the purposes of air quality. In terms of cooperation, Houston has an advantage in that despite the size of the metropolitan area, the number of core organizations actively involved in ITS and air quality management are relatively limited. The core ITS-air quality agencies include: one city (Houston), one county (Harris), one transit provider (Metro), the MPO (H-GAC), the state DOT (TxDOT), and the state environmental agency (TCEQ). As a comparison, even the much smaller city of Orlando (in population) has a slightly more complex institutional structure, with important participation in ITS from the private toll authorities, three

\textsuperscript{241} While Los Angeles saw the number of days with exceedances fall from over 160 to 40 or less a year between 1987 and 2001, during the same time period, Houston saw declines from approximately 50 days a year to approximately 40 days a year, with much more year-to-year variation in the number of exceedances (52 days in 1999 and 32 days in 2001). See figures and discussion in Chapter 5.

\textsuperscript{242} See Chapter 5 for the description of the interview and case study methodology used.

\textsuperscript{243} While the original attainment dates for 1-hour ozone were 2007, the attainment dates for 8-hour ozone (for which Houston is designated "moderate"), is June 15, 2010.
counties, the city, the transit provider, MPO, and state DOT. Moreover, the four core agencies that form TranStar – Houston, Harris County, TxDOT and Metro – have regular contact through their co-location in the TranStar facility, and through both regular meetings and informal interaction. Therefore, there is already a strong institutional basis, as well as established individual relationships, for cooperation on issues related to ITS.

In terms of cost, although Houston is one of the wealthier cities in the US, an interview with TxDOT suggested that the lower cost of ITS as compared to traditional capacity expansion was a factor in its high levels of deployment. As noted by an interviewee from TxDOT, “we really had no choice with ITS – there just wasn’t enough money to solve the capacity problems and air quality problems without ITS” (TxDOT interview, 2005).

Houston also has high levels of information regarding the air quality benefits of ITS. There are several reasons for this. First, the transportation agencies in Houston have developed many longstanding relationships with universities and other research institutions, in particular, with the Texas Transportation Institute. These relationships have served both to support deployment and evaluate planned and ongoing projects. Second, because TranStar and other ITS programs in Houston, such as the managed HOV/HOT lanes, have been seen as “cutting edge” in ITS implementation in the US, many researchers and policymakers have focused on Houston as a data source or case study, generating numerous reports and evaluations. Finally, in order to take advantage of the possible linkages between ITS and air quality, the transportation and air quality agencies in the Houston area developed a common sourcebook for evaluating the emissions impact of ITS and other mobile source emissions reduction measures. This sourcebook facilities the evaluation of ITS for air quality purposes, by developing methodologies that are accessible to large and small agencies. In addition, these methodologies do not require highly extensive modeling or data collection efforts, beyond the data that would ordinarily be collected for evaluation of mobility improvements.

The state of the seven conditions in Houston would suggest some of the highest possible levels of IIDAPT. The severity of Houston’s air quality and congestion problems would suggest that the problem should be critical enough to motivate substantial innovation with ITS as a measure to improve air quality. Houston’s size is large enough to have a high level of internal resources for air quality and transportation programs, as well a large inflow of dedicated resources, in the form of CMAQ funding, for experimenting with air quality-enhancing transportation projects. Cooperation should also be high, given the existence of mutual benefits for both air quality agencies looking for near-term emission reductions measures, as well as for transportation agencies, looking to further bolster support for existing or planned ITS deployments. Additionally, despite its size, Houston does not face major problems with fostering cooperation. Through the establishment of TranStar, it has already been able to create the institutional mechanisms for cooperation, at least between the key transportation agencies. Finally, there should be high levels of assessment and adaptation, both in response to internal and external evaluations, studies, and assessments of ITS deployments and their emissions impacts.

The Texas Transportation Institute (TTI) the largest university-affiliated state research agency in the US; it is affiliated with the Texas A&M University System.
Therefore, the conditions in Houston would predict high levels of IIDAPT across all four components – innovation, cooperation, assessment and adaptation (see Table 6-6). Houston had severe air quality and congestion problems, high levels of dedicated resources, strong internal resources (both for deploying technologies, and the analysis to make the link between ITS and air quality), and perceived mutual benefits. The number of agencies was also favorable to cooperation on new innovations, and institutional innovations for cooperation were established with TranStar. And, the large inflow of information on air quality benefits suggest adaptation should be high. We will now look in-depth at the actual ITS applications that have been deployed or adapted with an air quality objective in Houston.245

6.2.1.2 Actual IIDAPT in Houston

From the site visits, interviews, and the review of transportation and air quality plans and evaluations and assessments of the air quality benefits of ITS, Houston emerged as the most aggressive and innovative of our five cities in implementing so-called “win-win” solutions between air quality goals, mobility improvements and congestion reduction. As evidence of this, the cornerstone of Houston’s ITS deployment efforts – TranStar – has relied heavily on funding from the CMAQ program. In addition, many of the supporting TranStar elements have been incorporated into the state implementation plans for air quality as transportation control measures (TCMs) in the Houston-Galveston area. Although primarily focused on freeway and arterial traffic management, Houston has also drawn on advanced technologies to enhance traditional demand management strategies and, albeit to a lesser extent, to improve transit service.

We summarize the average level of IIDAPT and the range of IIDAPT in Table 6-4. The process for deriving these measures is described in Chapter 4, while the actual calculations are provided in Appendix E. However, we will briefly review the steps here. For each city, ten ITS application areas – three traffic flow improvement applications, three transit-based applications, multi-modal information, two demand-side applications, and other applications – are considered. Within each ITS application area, we assess the level of innovation for candidate IIDAPTs (this is calculated in Appendix E). In some cases, technologies do not qualify as IIDAPT, either because there is no innovation or cooperation between agencies in their deployment and/or adaptation. In other cases, they do not qualify as IIDAPT for ITS and air quality, because there is no identifiable air quality objective in the ITS deployments, or in fewer cases, because there is no mobility objective in their deployment.246 In both cases, they are listed as not applicable

245 To reiterate, air quality does not have to be the principal objective for an ITS deployment to be considered a case of IIDAPT. Indeed, the concept of IIDAPT focuses on technologies that attempt to generate benefits for more than one policy sector objective, in this case, mobility and air quality. We assert that the majority of IIDAPT examples for ITS will have air quality only as a secondary objective to mobility improvements.

246 As an example of the latter, an online smoking vehicle reporting system may represent the application of information and communication technologies to the transportation system to improve air quality outcomes. But, if there is no mobility benefit, it cannot be considered IIDAPT, because it has only a single policy objective. However, the reader may then ask question why these were still considered ITS, if there was no mobility benefit. This issue was addressed in Chapter 2, in the discussion of energy and emissions ITS applications. To reiterate, we consider applications to be ITS if they apply information and communication technologies to the transportation system to improve performance for any one of the five national ITS program goal areas: (1) safety, (2) mobility, (3) efficiency, (4) productivity, or (5) emissions and energy.

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In order to scale up from individual technologies, to multiple technology deployments in a metropolitan area, we take the average level of IIDAPT across the application areas, and the number of ITS application areas with IIDAPT for each city, as a measure of range.

Table 6-4 IIDAPT average level and range in Houston

<table>
<thead>
<tr>
<th>ITS application areas</th>
<th>Representative technology</th>
<th>IIDAPT scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arterial traffic flow improvements</td>
<td>RCTSS</td>
<td>4.5</td>
</tr>
<tr>
<td>Freeway management strategies</td>
<td>CTMS</td>
<td>4</td>
</tr>
<tr>
<td>Freeway traveler information</td>
<td>TranStar website</td>
<td>N/A</td>
</tr>
<tr>
<td>Transit information</td>
<td>METRO Trip planner</td>
<td>N/A</td>
</tr>
<tr>
<td>Multi-modal information</td>
<td></td>
<td>N/A</td>
</tr>
<tr>
<td>Transit operational improvements</td>
<td>IVOMS</td>
<td>N/A</td>
</tr>
<tr>
<td>Transit fare payment systems</td>
<td></td>
<td>N/A</td>
</tr>
<tr>
<td>Rideshare support</td>
<td>RideShare matching/mini-pool waiting list</td>
<td>4</td>
</tr>
<tr>
<td>Demand management/pricing</td>
<td>QuickRide HOT lanes</td>
<td>5.5</td>
</tr>
<tr>
<td>Other applications</td>
<td>Online Smoking Vehicle Reporting</td>
<td>N/A</td>
</tr>
<tr>
<td><strong>Average level (0-6)</strong></td>
<td></td>
<td>4.5</td>
</tr>
<tr>
<td><strong>Range of IIDAPT (0-10)</strong></td>
<td></td>
<td>4</td>
</tr>
</tbody>
</table>

In terms of the level of IIDAPT, the average for Houston is 4.5 out of a maximum of 6, which is high. Most of the individual applications showed a high level of innovativeness, cooperation, and assessment, although adaptation to new information was generally low. On the other hand, there is a low level of range in the use of ITS for air quality. Most of the experimentation with ITS for air quality in Houston has been concentrated in traffic flow improvements on roadways, and in different demand management strategies. Transit, on the other hand, has no cases of IIDAPT, according to our definition that the deployments must have air quality as one of the policy objectives. The use of transit ITS does not appear in state implementation plans for air quality, nor does it appear in lists of additional and/or voluntary measures for mobile emissions reductions.

In addition to the average level and range of IIDAPT, we also include a measure of intensity of IIDAPT, again described in Chapter 4. All measures of IIDAPT are shown together in Table 6-6. ITS utilized 27% of CMAQ funding (for FY 2005-2008), with ITS projects representing 44% of all recent CMAQ-funded projects. As suggested by the interviews, CMAQ has been an important source of funding for ITS deployments, in particular, for those deployments implemented through the TranStar program.
Table 6-5 Measures of IIDAPT for Houston

<table>
<thead>
<tr>
<th>IIDAPT measures</th>
<th>Average level</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intensity (share of CMAQ projects)</td>
<td>37/84</td>
<td>44%</td>
</tr>
<tr>
<td>Intensity (share of CMAQ funding)</td>
<td>$82 M / $306 M</td>
<td>27%</td>
</tr>
<tr>
<td>Intensity (share of 1994-9 TCM projects)</td>
<td>90/103</td>
<td>87%</td>
</tr>
<tr>
<td>Intensity (share of 1994-9 TCM funding)</td>
<td>$78 M / $96 M</td>
<td>81%</td>
</tr>
<tr>
<td>Intensity (share of post-2000 TCM projects)</td>
<td>40/139</td>
<td>29%</td>
</tr>
<tr>
<td>Intensity (share of post-2000 TCM funding)</td>
<td>$72 M / $679 M</td>
<td>11%</td>
</tr>
</tbody>
</table>

We also see that 29% of all TCM projects completed or still pending after 2000 are ITS-based projects, although this represents only 11% of the cost of all TCMs for the Houston region. The more interesting story, however, is that the vast majority (87%) of all TCM projects completed between 1994 and 1999 were ITS-based, accounting for 81% of total project costs for all TCMs during that time period. This major focus on emission reductions through ITS-based freeway and arterial management during the mid- to late-1990s reflects, in large part, the expansion of Houston’s computerized transportation management system (CTMS) for freeway traffic and incident management, and the Regional Computerized Traffic Signal System (RCTSS) for arterial traffic flows.

In the post-2000 period, ITS has continued to play an important role in the development of transportation control measures. However, there has also been a shift in emphasis away from ITS-based operational improvements, to capital investments, primarily for new transit projects, but also for more traditional transportation supply management measures. The deployment of Metro’s new light rail service in the downtown area, would be by far the biggest (and least cost-efficient) measure in the list of TCMs, with a cost of over $300 million. Transportation supply management (TSM) strategies such as turn lanes, grade separation, intersection improvement projects, and interchanges, represent another substantial portion (26%) of spending on TCMs, with $178 million of total TCM spending.

As in the earlier round of TCM deployment, transportation demand management (TDM) strategies – vanpooling and commute alternatives programs – would be the most cost-effective, with over 200 kg/day in reductions for the post-2000 TCMs (see Chapter 5). ITS has also supported many TDM strategies, and therefore are counted as part of the aggregate level/range of IIDAPT in Houston (see Table 6-4 and Appendix E). However, we do not include TDMs, such as ridesharing and transit, in the measure of intensity because the ITS features of these TDM and transit projects cannot be fully discerned from the project descriptions.

Summarizing Houston’s innovation with ITS for the purposes of both mobility and air quality, we can see that the levels, and more importantly, the intensity of use of ITS as strategy for air quality improvements, are high. TxDOT’s computerized traffic management system (CTMS) operated through TranStar and the regional computerized traffic signal system (RCTSS) have been heavily utilized as TCMs, taking ample credit for their emission reductions in the region’s air quality plans. In turn, they have received generous funding through the CMAQ program.
This was particularly true during the mid- to late-1990s when a large portion of the supporting hardware and communications network for these systems was being deployed.

Yet, there is very little range across modes in the use of ITS for air quality objectives, with most of the deployments falling within the category of either freeway or arterial traffic flow improvements. In contrast to the experience with ITS-based traffic flow improvements, there are no examples of transit ITS applications included as either TCMs or as CMAQ-funded projects. The one exception would be the integration of transit signal priority into the RCTSS system. However, signal priority is to a large extent an add on to what is predominantly an arterial traffic flow improvement project through interconnection and centralization of traffic signal control. During the 1990s, there were no transit TCMs. After 2000, there have been two transit TCMs, the major one being the deployment of MetroRail. However, because this is a fixed-rail service, the advanced technology components for operations are not generally considered ITS.  

Transit projects have been funded through CMAQ, although none of these have had an ITS component, and are primarily new bus and shuttle service or expansion of service, and fare operating subsidies. On the whole, relative to arterial and freeway ITS in Houston, deployment of transit ITS has lagged. Metro's bus fleet has been equipped with an advanced radio communications system to support operations since the late 1990s. Yet, Metro's integrated vehicle operations and management systems (IVOMS) project—which will incorporate GPS-based automatic vehicle location (AVL), passenger counting, mobile data terminal, and stop annunciators—is still in the final stages of deployment throughout its 1,300 fixed route bus fleet. This bias toward the use of ITS for air quality improvements via traffic flow improvements, with little focus on the use of ITS for air quality improvements via transit service improvements to boost ridership, is also reflected in earlier operations on CMAQ funding. Although targets had been set by H-GAC for spending on the different categories of CMAQ projects, actual spending for fiscal years 1996 to 2000 were higher than the target levels for both traffic flow improvements and demand management projects, while spending fell below target levels for transit and intermodal projects (Transportation Research Board 2002, p 250).

Despite the intensity of use of ITS, there appears to be relatively little fundamental adaptation of many of the ITS deployments used for air quality improvements, despite the high levels of information regarding those deployments and their emissions impacts. For example, although air quality impacts for the RCTSS and CTMS are measured both through ex-ante and ex-post analysis (using before and after studies of speeds, for example), there have been no attempts to use information on emissions changes to modify or adapt those systems to generate even greater air quality improvements. The assessments have also remained relatively superficial, failing to evaluate the two key uncertainties regarding the air quality impacts of traffic flow improvements: (1) the effect of induced demand and (2) the effect of reducing accelerations and decelerations in addition to changing average speeds. Although adaptation is a subtle characteristic of

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247 Again, ITS generally refers to the surface transportation system, and excludes modes such as rail, which generally utilized different signaling and control technologies.

248 By omitting analysis of the former, the emissions benefits may be overestimated. In contrast, by omitting analysis of the latter, the emissions benefits may be underestimated.
IIDAPT, and difficult to measure in a rigorous manner, it is an important component of IIDAPT, and reflects upon the underlying interests and motivations for agencies to undertake these types of innovations in the first place. We will discuss this point in greater depth below.

6.2.1.3 Comparison and Discussion

Comparing our predicted and actual levels of IIDAPT for the case of Houston, we find that the theory does indeed predict the high average levels and intensity of IIDAPT that are found in Houston (see Table 6-6). However, what the conditions did not fully predict is the lack of modal variation in the ITS applications that are deployed with an air quality objective. To understand this outcome, we have to look more closely at the interests and preferences of individual agencies, and how their interests and preferences have been influenced by the local context for decisionmaking. Understanding the interests motivating each agency will allow us to determine how mutual benefits are actually perceived by agencies, thus treating the concept of “win-win” situations in a more rigorous manner.

Table 6-6 Comparison of predicted and actual outcomes in Houston

<table>
<thead>
<tr>
<th>Theoretical Outcomes</th>
<th>Actual Outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seven conditions from theory</td>
<td>Summary: HIGH</td>
</tr>
<tr>
<td>1. Problem severity - high</td>
<td>• Innovation - high</td>
</tr>
<tr>
<td>2. Internal resources - high</td>
<td>• Cooperation - high</td>
</tr>
<tr>
<td>3. Dedicated resources - high</td>
<td>• Assessment - high</td>
</tr>
<tr>
<td>4. Cost - low</td>
<td>• Adaptation - high</td>
</tr>
<tr>
<td>5. Mutual benefits - high</td>
<td>Summary: HIGH (5.2)</td>
</tr>
<tr>
<td>6. Number of agencies - med</td>
<td>Average level * range * intensity</td>
</tr>
<tr>
<td>7. New information - high</td>
<td>4.5 * 4 * .29 = 5.2</td>
</tr>
<tr>
<td>Predicted outcomes based on seven conditions</td>
<td>Description:</td>
</tr>
<tr>
<td></td>
<td>High level of IIDAPT for arterial and freeways. Low for transit.</td>
</tr>
<tr>
<td></td>
<td>Moderate for TDMs. Generally high levels of assessment, but little adaptation. High intensity of use.</td>
</tr>
<tr>
<td></td>
<td>Quantitative measures:</td>
</tr>
<tr>
<td></td>
<td>• Average level: 4.5</td>
</tr>
<tr>
<td></td>
<td>• Range: 4</td>
</tr>
<tr>
<td></td>
<td>• Intensity: (2005-2008)</td>
</tr>
<tr>
<td></td>
<td>44% CMAQ projects,</td>
</tr>
<tr>
<td></td>
<td>27% of CMAQ dollars</td>
</tr>
<tr>
<td></td>
<td>(1994-1999)</td>
</tr>
<tr>
<td></td>
<td>87% of TCM projects</td>
</tr>
<tr>
<td></td>
<td>81% of TCM total project cost</td>
</tr>
<tr>
<td></td>
<td>(post 2000)</td>
</tr>
<tr>
<td></td>
<td>29% of TCM projects**</td>
</tr>
<tr>
<td></td>
<td>11% of TCM total project cost</td>
</tr>
</tbody>
</table>

* Again, the summary quantitative measure is a product of average level, range, and intensity. We will focus more on this specific measure when we do the cross-case comparisons.

**For intensity, we use the percentage of TCM projects in the most recent air quality management plan that include ITS. This is to ensure consistency across for cross-case comparisons (see Table 6-17).
First, we will discuss the case of ITS-based traffic improvements for air quality, specifically the regional computerized traffic signal system (RCTSS) and the computerized traffic management system (CTMS), the two major ITS technologies that have been used for emission reductions. Second, we will discuss the lack of transit ITS in Houston’s air quality initiatives. Third, we will review the use of ITS for supporting transportation demand management—the most cost-effective category of transportation control measures in Houston. Finally, we will review the use of assessment and integration of new information into future deployment and operations decisions. We will look at whether and how adaptation occurs, and why, or why not.

- **Claiming air quality credit (and money) for freeway and arterial ITS**

The cases of RCTSS and CTMS—as core strategies within the mix of transportation control measures and well-funded through the CMAQ program (particularly in the mid to late 1990s)—is relatively easy to explain with our theoretical framework. The key transportation agencies, TxDOT, the City of Houston, Harris County, and Metro, were in the process of deploying an extensive ITS infrastructure, primarily in the form of RCTSS for arterial traffic control and CTMS for traffic management on the freeways. They saw the potential benefits from highlighting the issue of air quality benefits in order to bolster support for their ITS efforts. The availability of CMAQ funds further reinforced this perception of mutual benefits to be gained from incorporating air quality objectives into the core ITS deployments in the region by adding a financial component. Therefore, the dedicated resources themselves created a strong mutual benefit to innovate using ITS for air quality purposes. Transportation agencies were eager to use these funds for their ITS projects, while the MPO was looking for ready-to-go projects that would be eligible for this funding category. In fact, looking at the linkages in Figure 6-1 on page 279, we might suggest that the linkages from problem severity, to dedicated resources, to mutual benefits and to both cooperation and innovation, were actually stronger than the direct link from problem severity to innovation.

The importance of CMAQ for ITS deployment and operations was underscored by an interviewee at TranStar, who suggested that “without CMAQ, we would be in trouble” (TranStar interview, 2005). Clearly, the transportation agencies had substantial benefits to gain from leveraging the linkages between congestion mitigation and air quality in their ITS program. CMAQ represents an important funding source for ITS, in large part because it is protected from use for traditional highway projects, but also because as a federal program funding category, it is not as susceptible as Congressional earmarks to political vicissitudes at the federal level.²⁴⁹

It is difficult to comment on the so-called “purity” of the intentions, however, in terms of whether ITS is used for air quality (through TCMs), or air quality is “used” for ITS (through access to CMAQ funding). For example, an interesting question is whether RCTSS and CTMS would have been included as TCMs in the absence of CMAQ funding. However, for insights into this question we also have to look more closely at the interests and preferences of the TCEQ and H-GAC, and how they align to generate mutual benefits.

As discussed in Chapter 5, during the process of SIP development, the Texas Commission on Environmental Quality shifted from more behavioral-based strategies, to more technology-based strategies. Specifically, in the 1997 SIP revision, TCEQ's preference toward technology-based strategies was clear in their inclusion of many technology-based TCMs – primarily signalization, traffic and transportation management strategies – in order to make up for the loss of the employee trip reduction program and a scaling back of the I/M program, two behavior-based strategies. Therefore, given that “the commission has expressed a preference to implement technology-based strategies over behavior-altering strategies,” using ITS to reduce emissions by changing traffic flow, and not motorist behavior, would neatly match the organizational preferences of TCEQ (Texas Commission on Environmental Quality 2004, p 17). Given that the political climate was not as friendly toward behavior-based measures or toward transit, as will be discussed below, it was also in the interest of the TCEQ to identify measures that would be considered acceptable to political leaders.

These organizational preferences and interests are also conditioned by the broader political context of Houston. More than any of the other case studies, the interviewees referred to the politics of the region as critical to understanding transportation and air quality decision-making. Both the mayors and the commissioners have been described as “enthusiastic” and “champions” of ITS. Indeed, this reaches up to the federal level as well, in particular, through the U.S. House Representatives from Sugar Land, Tom DeLay, and from Houston, John Culberson. Delay was active in the early years of the ITS program, and advocated for the inclusion of Houston as one of the four ITS Priority Corridors in ISTEA, which meant a substantial allotment of earmarked federal funding for ITS deployment in Houston. They have not, however, been champions for transit. In Washington, Delay and Culberson “blocked some efforts for federal funding of Metro’s light rail line,” while at the same time they “championed road and automobile-related projects,” including those incorporating ITS. However, there has been a major shift in the past several years. As voters approved the Metro Solutions plan for significant expansion of transit, federal leaders changed their earlier stance toward transit funding. In fact, some of the same leaders that earlier blocked federal funding for transit in Houston, later were the same players that were help secure funding for the Metro Solutions plan.

- **Pushing for rail at Metro**

As noted earlier, the use of ITS for air quality objectives is dominated by arterial and freeway traffic flow improvements in Houston. However, there are clearly ITS applications for transit in Houston that have potential air quality benefits. Houston has deployed a number of transit ITS applications, such as electronic fare payment and advanced radio communications systems, and is in the process of deploying multiple ITS components bundled together in the Integrated Vehicle Operations and Management System (IVOMS). However, there has been no successful effort by agencies to use or identify transit ITS technologies as measures to improve air quality,

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either through better operations (i.e. less idling time, fewer accelerations for buses) or through changes in ridership, and thus reductions in VMT for private automobiles. As a result, we do not find ITS-based transit improvements in either the list of TCMs or CMAQ-funded projects. Although there were a few transit projects incorporated in earlier CMAQ funding rounds, they were primarily programs such as expansion of bus and shuttle services, and some transit fare/pass subsidy programs, not ITS.

Again, these outcomes depend upon the interests and incentives for individual agencies to promote ITS (or not) as viable emission reductions measures, underscoring the importance of the mutual interests in deploying these technologies. The motivations for TxDOT, the City of Houston, and Harris County to prefer focusing on arterial and freeway measures for air quality improvements were discussed above. However, the question is why Metro, first and foremost a transit agency, did not push for greater inclusion of ITS initiatives, such as IVOMS, into the list of TCMs, or for greater funding from CMAQ? On the contrary, Metro has used CMAQ funds to support what is primarily a traffic signal upgrading, interconnection, and optimization project – RCTSS – although it will incorporate transit signal priority as well. In part, the reason lies in the multiple mandates that Metro must fulfill. Although Metro serves as the area’s transit service provider, it also has important responsibilities in addition to transit service, including management of the HOV lanes and QuickRide program, the Motorist Assistance Program, as well as local street construction. In fact, 25% of the local sales tax revenue must be dedicated to the General Mobility Fund for infrastructure improvement projects on local streets and bridges. Given these multiple mandates, it is not surprising that Metro would support projects such as the RCTSS, a signal upgrading, interconnection and retiming project, that also incorporates signal priority capability.

The use of ITS for air quality would also be influenced by Metro’s interest in advancing its agenda of deploying rail. Indeed, since the early 1980s, following the passage of a local sales tax for transit and the formation of Metro in 1978, there has been controversy in Houston over the possibility of constructing a rail system (first considering heavy rail, then shifting to a focus on light rail). Beginning in the 1990s, Metro began to push forward with its plan, Metro Solutions, an aggressive plan for expanded transit service, including bus, light rail, bus rapid transit, bus/HOV lanes, and commuter rail. Metro planners had earlier developed a proposal for a monorail project – a plan which was “quashed” by Mayor Bob Lanier when he came into office in 1991. Similarly, the proposals for light rail were not generally supported, and at times, actively opposed by key political leaders at both the local and federal level. Yet, Metro and

252 Because the CMAQ and other federal funds for the Metro’s RCTSS program come from the Federal Transit Administration, signal priority must be incorporated for it to be an eligible transit project. However, the bulk of the effort put into the RCTSS program is focused not on the signal priority component, but rather on the upgrading and interconnection of the signals and controllers. Therefore, while there will be transit benefits through signal priority, the bulk of the benefits will be through arterial traffic management and linking the signal back to the TranStar facilities, where they will be managed by the City of Houston, Harris County and TxDOT.

253 See Altshuler and Luberoff (2003) for a concise account of Houston’s proposals for rail and the ensuing political controversies (p 208-209).

254 Lucas Wall, “Signal system hits more snags; 5 years past due, Metro’s project to link traffic lights to control center may be ready in April.” The Houston Chronicle, page A-1.

293
transit advocates continued to push the light rail concept, supported in part by environmental and other interests which had long been advocating shift in emphasis from road building to transit investment. Their efforts came to fruition in 2001, as Metro broke ground for its first light rail, the MetroRail (designated the “Red Line” in anticipation of additional lines). Metro also received an additional affirmation of their long range expansion plan, Metro Solutions, when the plan’s referendum was approved by voters in November 2003. This also led to a significant change in the attitudes of US congressional representatives, who, as described earlier, then moved to secure additional federal funding for light rail in Houston.

Therefore, Metro’s interest has been in securing support from the public and elected officials for an ambitious light rail expansion project. During the 1980s and 1990s, several iterations of plans for heavy rail, monorail, light rail and bus were developed and rejected, at times by voters, and at times by local and federal elected leaders. As Metro planners built up the case for major investment in the capital infrastructure needed for rail, their incentives for highlighting possibly cheaper and viable alternatives, such as ITS-supported bus rapid transit systems, would be low. Indeed, when Mayor Lanier took office in 1991, he moved toward an all-bus option, replacing the older bus fleet and building additional HOV lanes for vanpools and buses. Although Metro was also working to improve bus operations and service through ITS, these improvements were not highlighted as air quality benefits, nor was funding from the CMAQ program sought. Instead, the focus was to highlight not the air quality benefits from better bus services, but rather the air quality benefits from light rail, which were included as a transportation control measure in the 2002 SIP revision, even though these project performed poorly in terms of the cost-effectiveness of emissions reductions (see Chapter 5). The inclusion of the light rail line as a TCM in the 2002 SIP may have been a strategic move on the part of Metro. The downtown to Astrodome light rail project first appeared as an “additional TCM” commitment in the December 2000 conformity demonstration, when the light rail project was in preliminary engineering. Inclusion of the light rail as a TCM essentially helped lock the region in to following through with the deployment of this project, since “failure to implement TCMs according to schedule can be grounds for the denial of an area’s transportation conformity determination,” which, in turn, could ultimately delay the flow of federal transportation dollars to the region (Texas Natural Resource Conservation Commission 2000, pp 6-27 to 6-28).

Ironically, failing to emphasize bus rapid transit – enhanced through a number of ITS technologies similar to those being deployed as part of the IVOMS project – as a high quality and viable alternative to rail, may have backfired in the recent changes to later phases of the Metro Solutions plan. Phase II of Metro Solutions – in an attempt to expedite the delivery of new, fixed-guideway transit service – has incorporated bus rapid transit, which would operate the routes initially, then be converted to rail transit once sufficiently high levels of ridership are reached. Yet, the public response has not been altogether favorable, as many, particularly rail

advocates, had viewed this as a watering down of the original Metro Solutions plan that was approved in the referendum.

- **HOV and rideshare matching**

Finally, we look at the use of online rideshare matching and demand management on the HOV lanes through pricing, and the mutual benefits from focusing on supporting HOV as an important air quality measure.\(^{257}\) Due in large part to the extensive HOV lane network in Houston, and the significant travel time savings that the use HOV network can provide, vanpooling and carpooling in Houston has been highly successful. As a tool for air quality improvement, the vanpool, carpool, and minipool programs, including the supporting online and phone-based ridematching services, have consistently been the most cost-effective category of TCMs.

Houston has also been innovative in pioneering the use of value pricing, with the deployment of the Katy Freeway HOT lane (for 2+ carpools during peak travel). Again, there were strong mutual benefits to the agencies involved in this project. TxDOT would benefit from providing some congestion relief by expanding the use of the HOV lanes and allowing smaller carpools to access the lanes for a toll. The toll agency, HCTRA, would benefit through the expansion of its tolling program, and gain an important foothold by expanding service to the HOV lane network. Metro was able to better utilize its HOV lanes, and received additional revenue from the tolled operation of the HOV lanes. Federal funding, through the value pricing program (a dedicated resource) was also an important motivator for these three agencies to collaborate on an innovative HOT lane idea.

However, by contrasting the success of the rideshare program, and indeed, the fact that there are waiting lists for a large number of vanpools along important routes, it seems counterintuitive that there would be such a need to move toward a HOT lane approach. This is based on the assumption that the capacity will not be fully utilized without allowing lower occupancy vehicles to use the lane, which by extension, assumes that the maximum limits of carpool, minipool, or vanpool opportunities has been reached. Yet, experience with the HOV network in Houston has shown it to be highly effective in initiating ridesharing, and that indeed, there are some apparent scale economies in having both a large network of HOV lanes, and a large pool of rideshare matching possibilities available. Institutional support for the ridesharing program has continued. However, the recent emphasis on expanding the “managed lane” concept (and thus reducing the occupancy requirements, which could undermine ridesharing) indicates that there is also strong institutional support for HOT lanes. If ridesharing loses ground to the managed lanes concept, allowing lower-occupancy vehicles for a toll, this can be construed as evidence that the organizational interests are better fulfilled by HOT lane implementation, than by pushing for more ridesharing.\(^{258}\) The organizational benefits come from the ability to better control service

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\(^{257}\) Indeed Metro promotes the HOV lanes as important for air quality. “Built primarily for buses, the HOV also promotes ridesharing through vanpools and carpools, which reduce traffic congestion and provide cleaner, healthier air throughout the region” [www.ridemetro.org/TransportationServices/Carpool_Vanpool_Services/HOV_system](http://www.ridemetro.org/TransportationServices/Carpool_Vanpool_Services/HOV_system). Last accessed April 8, 2006.

\(^{258}\) There do not appear to be in-depth studies looking specifically at the potential impact on carpooling by the conversion of lanes from pure HOV operations to HOV/Toll (or HOT lane) operations, also referred to as managed...
levels on the HOV lanes through pricing, and from the additional revenue that tolling HOV lanes can create.

- **Assessing the impacts**

Now that we have discussed in depth the concept of mutual benefits, and how that has influenced the patterns of use of ITS for air quality in Houston, we will now look at the role of new information and assessment in promoting adaptation of those innovations. Compared to other regions, such as Los Angeles, the tacit consensus between transportation professionals, and to a large extent air quality analysts in Houston, seems to be that mitigating congestion improves air quality. According to H-GAC, even in earlier years of deployment, ITS “was an important tool for our air quality strategies, although early on, none of us were sure how much benefit we could get from that – from an air quality perspective – until we had some opportunity to use it” (H-GAC interview, 2005). Therefore, from the beginning, there was a willingness to experiment with the use of ITS to generate emission reductions, even when uncertainty regarding those reductions was high.

Of all the cases, Houston was the only one to utilize a single guidebook with uniform and consistent methodologies for measuring and documenting the emissions reductions from a wide range of “accepted” emissions reductions measures. Therefore, this handbook improves the confidence of both transportation and air quality agencies that the analytical and regulatory basis for using ITS applications for emissions reductions are sound. Therefore, there is a certain confidence that these are acceptable measures to improve air quality, even through the benefits may be overestimated. Indeed, the Texas Guide to Accepted Mobile Source Emission Reduction Strategies (or MoSERS guidebook) also seems to have supported greater levels of deployment of ITS for air quality – largely along the same lines as earlier innovations – but without adaptation of ITS deployments to new information regarding the air quality benefits of those deployments. For example, the use of the MoSERS manual facilitates the use of CMAQ funding by the City of Houston for its projects, by providing an accessible guide to measuring and documenting the air quality benefits. Given the City of Houston does not have the size and internal resources of Metro and TxDOT, the ability to use MoSERS facilitates access to CMAQ funds by the City of Houston, which must compete with larger agencies for this funding category.

However, MoSERS may serve to reinforce the use of existing ITS strategies as TCMs and as eligible for funding through the CMAQ program, rather than to attempt to reduce some of the key uncertainties regarding the air quality impacts of ITS. It does not create “truly” new

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259 The other cases may have had similar handbooks or guides, however, Houston was the only case in which interviewees consistently referenced the same source.

260 However, the literature on the “social construction” of knowledge would tell us that agreement on methodologies for technical analysis does not necessarily mean that those methodologies are the best or most accurate representations of reality. It simply reflects that a consensus has been reached by the relevant actors on what is a “good” or “acceptable” methodology.
information regarding the air quality impacts of ITS deployments, or attempt to validate that the purported emissions reductions are indeed occurring, for example, by directly measuring changes in concentrations along effected corridors. Rather, it is a manual for documentation of benefits (which may or may not accurately reflect real benefits).

6.2.1.4 Conclusion

To summarize, comparing our predicted and actual levels of IIDAPT for the case of Houston, we find that the theoretical framework does predict the high levels of IIDAPT. We see high levels and intensity of IIDAPT in Houston, particularly for freeway and arterial ITS (see Table 6-4 to Table 6-6). However, what the seven conditions alone cannot fully predict is the lack of modal diversity or range of the ITS applications that are deployed with an air quality objective, and why there is so little IIDAPT in the area of transit, despite the recent deployment of several ITS applications for transit. This does not change our basic theoretical construct and the seven conditions, but it does point us toward certain conditions that appear to be more important than other conditions.

To understand these outcomes, we needed to look more closely at the mutual benefits that the various agencies can derive from different ITS solutions, and how that is influenced by the broader context of transportation planning, politics and investment in the Houston region. These agency interests aligned in favor of using ITS for freeway and arterial traffic flow improvements, and for advancing the air quality benefits of those ITS applications. ITS was seen as an important congestion mitigation component, and one that was compatible with the agenda of continued highway expansion. The general consensus among agencies, as affirmed by the MoSERS manual, was that these activities were nearly always supportive of air quality objectives. That was used, in turn, to access substantial amounts of CMAQ funding for ITS. However, agency interests did not align in favor of promoting the use of ITS in transit as a measure for air quality improvements. Because the preferred option, on the part of the transit agency, for transit investments was light rail, it did not necessarily want to highlight the ability of ITS to provide levels of service and air quality benefits competitive with those provided by light rail, and therefore detract from the campaign to deploy and expand Houston’s emerging rail system.

The seven conditions predicted the high average levels of IIDAPT, and the high intensity of IIDAPT in Houston. However, in order to explain outcomes more satisfactorily, particularly the lack of transit ITS for air quality purposes, we had to focus more closely on how mutual benefits between agencies were perceived, and how the broader local context had influenced agency interests and preferences. The lesson that emerged here is that mutual benefits between agencies cannot be described using their policy objectives and goals (i.e. improve mobility and traffic flow, improve transit ridership and mode share, improve air quality). Rather, these mutual benefits must be understood and defined in terms of agencies’ preference for certain types of investments over others (i.e. light rail over bus rapid transit), and whether ITS will support or detract from building the case for those investments. Therefore, while these results do not change the structure of our theoretical construct, they highlight which conditions are more important, such as problem severity, mutual benefits, and dedicated resources. The results also
suggests where some of the conditions, particularly mutual benefits, need to be defined more rigorously. For identifying areas of mutual benefits, it is important to take into account how the local context and agency agendas and interests can shape what agencies perceive to be mutual benefits or not from a particular technology.
6.2.2 Los Angeles

We now turn to the case of Los Angeles. Although the summary indicators suggested that levels of ITS deployment in Los Angeles were only moderate, the site visit indicated that levels were actually very high, particularly when factoring in how effective or advanced the deployed systems are, as well as taking into account the size of the Los Angeles region. Compared to Houston, Los Angeles has even more critical air quality and congestion problems, and similarly high levels of ITS deployment in place. Yet, as will be discussed in-depth below, the case of Los Angeles diverges from the experience in Houston, in that the region has not been either willing or able to claim full credit for the possible air quality benefits that may have been created by many of its ITS deployments.

6.2.2.1 Conditions and Predicted IIDAPT in Los Angeles

Los Angeles is the only metropolitan area (of our five case studies cities) to have a non-attainment designation of extreme for 1-hour ozone, and has consistently had the worst congestion in the nation. Therefore, simply in terms of problem severity, we would expect Los Angeles to have very high levels of IIDAPT, using ITS to achieve the dual objectives of air quality and mobility improvements. Furthermore, because of its large population and extreme non-attainment designation, Los Angeles received the highest levels of CMAQ funding in the nation. For example, in fiscal year 2000-1, the apportionment was nearly $220 M—meaning that the level of dedicated resources is also extremely high. Internal resources are also very high, with an MPO staff (Southern California Association of Governments, or SCAG) of over 100 employees, and nearly 40 in the area of transportation, environmental and community planning. Transportation agencies in the region are also large. For example, LA’s largest transit provider, Metro employs over 9,000 people.

Yet, while the conditions for innovation would suggest very high levels of innovation with ITS for air quality, the prospects for cooperation on innovations dealing with both mobility and air quality concerns are not as encouraging. Los Angeles is the most institutionally complex of the case study cities, with multiple layers of agencies responsible for both transportation and air quality management and planning. For example, air quality issues must pass not only through

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261 To take a stylized example, two cities can have 50% of their signalized intersection under centralized or close loop control. However, one of the cities may control those signal through a highly advanced adaptive signal control software based upon real-time traffic conditions, while other cities only use their centralized signal control for remotely reprogramming signals or identifying signal outages, etc. Similarly, a city with 50% of fixed-route buses accepting electronic fare payment can only accept certain weekly or daily magnetic strip passes, or contactless smart cards with either passes or rechargeable prepaid amounts. As discussed in Chapter 5, the size of the Los Angeles region means that ITS deployment as a percentage “coverage” of physical capital infrastructure can lead to an underestimation of the levels of ITS deployment.

262 Although Houston has rivaled Los Angeles for the number of high ozone days, Los Angeles has generally held on to first place in smog. Miguel Bustillo, “L.A.’s the Capital of Dirty Air Again,” Los Angeles Times, part B, page 1, November 15, 2005.

263 Fresno, California, an inland metropolitan area located in the San Joaquin Valley, was also designated extreme non-attainment for 1-hour ozone.
the state-level California Air Resources Board (CARB), but also the regional air quality districts, such as the South Coast Air Quality Management District (SCAQMD). While in other metropolitan areas, the transportation agencies work with the MPO on developing transportation control measures, and submit those directly to the state environmental agency for inclusion in the SIP, in Los Angeles, there is the additional involvement of the air quality district. Therefore, many of the local transportation control measure receive substantially more review by air quality agencies than in other cities, where the development of TCMs is delegated more fully to the transportation agencies and MPOs. In this sense, Los Angeles is the most fragmented and decentralized of the five metropolitan areas, and we would therefore predict that cooperation would be substantially more difficult.

Regarding the conditions for adaptation, there is a substantial amount of research regarding ITS and air quality in the Los Angeles region, consisting of both internal and external assessments and analyses, and peer-reviewed academic research. The California Partners for Advanced Transit and Highways (PATH), for example, is a multi-disciplinary research program administered by the Institute of Transportation Studies at the University of California at Berkeley, and Caltrans. 264 Indeed, with a mission of “applying advanced technology to increase highway capacity and safety, and to reduce traffic congestion, air pollution, and energy consumption,” the PATH program seems to be highly relevant to the use of ITS for air quality improvements. In addition to PATH, the University of California system has a number of smaller research programs for transportation and air quality, and many of the nationally recognized experts regarding the air quality impacts of ITS and other traffic flow improvements are located in California.

6.2.2.2 Actual IIDAPT in Los Angeles

If we only considered the severity of the problems of congestion and air quality, the worst in the nation on both accounts, one would expect the transportation and air quality agencies in LA to be the most active in finding synergies between ITS and air quality. Indeed, IIDAPT levels are relatively high in terms of the average level and very high on range, as seen in Table 6-7.

264 PATH has 45 full-time staff members and supports the research of nearly 50 faculty members and 90 graduate students. See www.path.berkeley.edu/PATH/General/statement.html. Last accessed April 1, 2006.
### Table 6-7 IIDAPT level and range in Los Angeles

<table>
<thead>
<tr>
<th>ITS application areas</th>
<th>Representative technology</th>
<th>IIDAPT scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arterial traffic flow improvements</td>
<td>ATSAC/ATCS</td>
<td>5.5</td>
</tr>
<tr>
<td>Freeway management strategies</td>
<td>ATMS/ATIS for Ports</td>
<td>2.5</td>
</tr>
<tr>
<td>Freeway traveler information</td>
<td></td>
<td>N/A</td>
</tr>
<tr>
<td>Transit information</td>
<td>Transit trip planning tools</td>
<td>3</td>
</tr>
<tr>
<td>Multi-modal information</td>
<td>CommuteSmart.info</td>
<td>4</td>
</tr>
<tr>
<td>Transit operational improvements</td>
<td>AVL/comm. systems</td>
<td>2.5</td>
</tr>
<tr>
<td>Transit fare payment systems</td>
<td>Universal Fare systems</td>
<td>4.5</td>
</tr>
<tr>
<td>Rideshare support</td>
<td>Ridematch.info</td>
<td>4.5</td>
</tr>
<tr>
<td>Demand management/pricing</td>
<td>SR 91 HOT lane</td>
<td>4</td>
</tr>
<tr>
<td>Other applications</td>
<td></td>
<td>N/A</td>
</tr>
</tbody>
</table>

Average level (0-6) **3.8**  
Range of IIDAPT (0-10) **8**

Probably the most innovation has occurred in the area of traveler information, specifically for ridesharing (ridematch.info) and multi-modal traveler information with commuter alternatives (commutesmart.info). For all of the case study cities, these are the best examples of integrated and real-time information for multiple modes, and comprehensive information for ridesharing. This matches the rhetoric of Southern California Association of Governments (SCAG) and the Southern California Economic Partnership (SCEP, or the Partnership) regarding Information-based Transportation Strategies, and suggests that the focus is indeed on improving the information content of the transportation network in ways that can lead to behavioral and modal shifts that benefit air quality and the environment. This is an innovative approach in that it employs technology in order to generate behavioral change. In comparison, Houston—with the exception of its similar online rideshare matching service and QuickRide HOT lanes—has focused on the use of technology to manage traffic flows in ways that improve air quality, but without requiring any fundamental shift in traveler behavior.

Los Angeles also stands out in the innovativeness of its ATSAC system for traffic signal control, developed by the City of Los Angeles, which has undergone continual innovation with the evolution toward adaptive signal control, and integration of transit signal priority, and steps toward incorporating real-time information on pollution concentrations from air quality monitors.\(^{265}\) However, in terms of intensity, traffic signalization strategies are not nearly as widely “counted” as possible emission reduction strategies, as they are in Houston.\(^{266}\) Cooperation was actually somewhat higher than expected, with high levels of cooperation in the deployment of the Universal Fare System, integrating fare payment media into a single smart card for nearly all public transit agencies in Los Angeles County, as well as cooperation in integrating transit planning and rideshare database information.

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\(^{265}\) As described in the Chapter 5, the integration of real-time air quality information was never fully implemented.

\(^{266}\) Therefore, even though traffic signalization improvements may provide some air quality benefits, they are not generally included in air quality plans as emission reductions measures. They are however, funded at times through the CMAQ program.
While the average level of IIDAPT for individual applications is high, and there is a range of applications, our measures of intensity of use of ITS for air quality are lower than those seen in Houston (see Table 6-8). This suggests that although there are a number applications that could qualify as IIDAPT, ITS is not as prominent either for CMAQ funding, or as a transportation control measure.

| IIDAPT measures                                      | Average level | 3.8
|------------------------------------------------------|---------------|-----
| Range                                                | 8             |
| Intensity (share of 2004-9 CMAQ projects)            | 49/214        | 23%
| Intensity (share of 2004-9 CMAQ funding)             | $184 M / $1,154 M | 16%
| Intensity (share of post-2002 TCM projects)          | 34/268        | 13%

In terms of intensity, only 49 of 214 CMAQ-funded projects include some ITS components. However, looking at the funding, ITS projects rank substantially lower with only 16% of all CMAQ funding going to projects with ITS. It should be kept in mind that these are CMAQ projects with an ITS component, not ITS per se. Of those (49) ITS projects that are funded with CMAQ, there is a relatively even split between ITS applications for transit (22) and for traffic flow improvements (25). For CMAQ-funded ITS projects aimed at traffic flow improvements, they are almost entirely signal connection, synchronization, and interconnection projects, and are mostly located in San Bernardino county. CMAQ-funded transit ITS projects include the universal fare system mentioned above, as well as advanced communications systems and automated vehicle location.

ITS applications appear with even less frequency for transportation control measures, with only 34 of 268 TCMs including an ITS element. As discussed in Chapter 5, the new categorization of TCMs for the most recent air quality management plan includes what are called Information-based Transportation Strategies, with ITS falling within that group. Only two of the 34 ITS-based measures are for traffic flow improvements—a traffic management system for the Pacific Coast Highway, and an automated traffic management system for the City of Corona. The rest are for transit improvements, ridesharing, and HOT lanes and value pricing.

In large part, this reflects the fact that the state DOT, Caltrans, plays a much smaller role in the CMAQ program than in other areas. In contrast to the case of Houston, where the TxDOT contracts out a large number of ITS projects for emission reductions from traffic flow improvements using CMAQ, Caltrans does not use CMAQ funding on ITS projects. In general, Caltrans does not have a large number of projects using CMAQ, and those projects that it does fund with CMAQ, are nearly exclusively HOV lanes.

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267 The other two projects are for bicycle detection in Los Angeles and database support for rideshare matching in Orange County.

268 For CMAQ funded projects for FY 2004/5 – 2009/10, Caltrans was the lead agency for only one ITS project, which was the installation of fiber optic cable in Ventura County.
6.2.2.3 Comparison and Discussion

The actual IIDAPT outcomes confirmed what the conditions predicted, as seen in Table 6-9. There was a medium-high average level of IIDAPT (3.8). The range of IIDAPT in Los Angeles was very high, much more so than in Houston, with examples of IIDAPT for eight out of the ten applications areas. However, the intensity of use of ITS using CMAQ funding, or as a TCM, was lower than would have been expected. Also, it is not clear why there was so little CMAQ funding used for ITS-based traffic flow improvements, and almost no inclusion of ITS-based traffic flow improvements as transportation control measures in the region’s air quality plan.

Los Angeles therefore presents an interesting case for why certain categories of ITS were not more aggressively used for air quality purposes, given that overall levels were high. For the case of Houston, we discussed why certain ITS technologies for bus rapid transit service were not used as TCMs, even though they were being deployed and had legitimate air quality benefits. In the case of LA, the “missing” applications are arterial and freeway ITS. Although we include a representative technology for freeway management strategies for our measures of IIDAPT in Table 6-7, there are only two ITS-based TCMs which are deployed to improve general traffic flow. Indeed, the vast majority of IIDAPT for ITS and air quality was for transit and ridesharing. This was true both for the region’s TCMs and for current CMAQ funding. This same dynamics also seems to play out with earlier CMAQ funding allocations, where transit projects represented the majority of the use of CMAQ.

**Table 6-9 Comparison of predicted and actual outcomes in Los Angeles**

<table>
<thead>
<tr>
<th>Theoretical Outcomes</th>
<th>“Predicted” outcomes based on seven conditions</th>
<th>Actual Outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Seven conditions from theory</strong></td>
<td><strong>Summary: MEDIUM to HIGH</strong></td>
<td><strong>Summary: MEDIUM-HIGH (4.0)</strong></td>
</tr>
<tr>
<td>1. Problem severity – high</td>
<td>• Innovation – high</td>
<td>Average level * range * intensity</td>
</tr>
<tr>
<td>2. Internal resources – high</td>
<td>• Cooperation – med</td>
<td>3.8 * 8 * .13 = 4.0</td>
</tr>
<tr>
<td>3. Dedicated resources – high</td>
<td>• Assessment – high</td>
<td><strong>Description:</strong></td>
</tr>
<tr>
<td>4. Cost – low</td>
<td>• Adaptation – high</td>
<td>High levels of IIDAPT for transit,</td>
</tr>
<tr>
<td>5. Mutual benefits – high</td>
<td></td>
<td>multi-modal and ridesharing info.</td>
</tr>
<tr>
<td>6. Number of agencies – high</td>
<td></td>
<td>Medium levels of IIDAPT for traffic flow improvements.</td>
</tr>
<tr>
<td>7. New information – high</td>
<td></td>
<td>High range, low intensity.</td>
</tr>
</tbody>
</table>

**Quantitative measures:**
- *Average level: 3.8*
- *Range: 8*
- *Intensity:*
  - (2004-9) 23% CMAQ projects,
  - 16% of CMAQ dollars (post 2002)
  - 13% of TCM projects
Therefore, the question is how to reconcile the innovativeness with ITS, and range of use in ITS for air quality purposes, with the low intensity of use? Another question, is why there is a lower level of use of ITS for air quality improvements from traffic flow improvements in air quality management plans. Los Angeles has a much smaller number of congestion mitigation and operations measures in its portfolio of ITS measures for air quality than one would expect, given its congestion and air quality problems. Most ITS technologies used for air quality purposes are for transit. Despite the advanced freeway and arterial management systems in place in Los Angeles, very few of these technologies are incorporated as TCMs, although some is deployed with funding from the CMAQ program (specifically, extensions of the ATSAC system). So, for those ITS applications that are known, or strongly suspected, to have air quality benefits, why is it that the project implementers have not taken credit for those emissions reductions?

- “Taming the automobile”

In large part, this use of ITS reflects the much broader changes in transportation policy direction in the Los Angeles region. As described by Wachs, beginning in the 1980s, the region initiated new programs and investments aimed at “taming the automobile” rather than accommodating its use through continued expansion of the freeway network (Wachs 1993, p 6). The focus was therefore on aggressive expansion of transit and transportation demand management strategies. In terms of the expansion of highway capacity, the emphasis was shifted toward expanding the network of HOV lanes, and addressing some of the “gap closure” projects to connect important links in the complex freeway network of Los Angeles. This major shift in transportation policy would greatly affect how transportation agencies would chose to use ITS as an air quality tool.

Perhaps the agency most affected by this shift in direction was Caltrans, which had to transform itself from a highway organization to a broader transportation agency. Indeed, there have been fundamental changes in the organization. An interviewee from Caltrans emphasized that Caltrans in no longer “just highways,” with involvement in park and ride lots, HOV, traveler information, and oversight for air quality impacts of local systems projects (Caltrans interview, 2005). Caltrans has a long history of ITS deployments, having begun with technologies such as ramp metering in the 1970s. While early applications started with a strong modal focus on highways, with detector loops, cameras, ramp metering, and variable message signs all feeding back into to the Transportation Management Center (TMC), emerging applications, such as the Regional Integration ITS (RIITS), are more multi-modal. Discussions with Caltrans highlights how they conceptualized the important changes in the core functions of the transportation management center, “the TMC is going to be an information center in the future, [to] collect and disseminate information to the general public. That’s where we’re heading” (Caltrans interview, 2005).

Caltrans clearly has made important organizational changes, first in its shift toward a more multimodal and systems focus, and second in its shift in emphasis from using ITS to directly manage traffic, to using ITS to indirectly “manage” travel by collecting and disseminating real-time information to the general public. Yet, although Caltrans has undertaken some important organizational innovations, the agency still has to deal with a legacy of cynicism on the part of environmental stakeholders regarding its ability to be environmentally responsible. Criticisms of
ITS arose from researchers such as Robert Cervero, who envisioned the use of ITS to only further exacerbate the problem of urban sprawl (Cervero 1995). Similarly, in a 1996 forum on ITS and the environment, focus groups “revealed a palpable skepticism... about the ability of Caltrans to adequately address environmental and social issues as part of its ITS program” (Horan, Hempel et al. 1996). Therefore, while Caltrans has deployed a wide range of ITS applications, it has very little incentive to attempt to push the air quality benefits of those deployments. According to SCAG, efforts to claim air quality credit for ITS improvements to traffic on Los Angeles’ freeways would probably not convince most members of the environmental community. In addition, as will be discussed below, the Los Angeles region has powerful air quality agencies, which, as suggested by interviewees, have not viewed operational improvements from ITS favorably, typically citing the induced demand argument. Indeed, interviews with project managers at Caltrans suggested that there was not actually a high level of internal awareness regarding the possibilities for induced travel from ITS-based improvements (see quotes from Chapter 5). In fact, this may corroborate some of the concerns cited earlier in the 1996 forum on ITS and the environment, regarding the ability of Caltrans to effectively address environmental and air quality concerns in the design and deployment of ITS. The end result is that despite the large number of ITS projects deployed by Caltrans, many of which may have legitimate air quality benefits, the agency does not have the incentive to claim credit for those freeway projects in terms of air quality in a planning environment that has decisively rejected freeway expansion.

While the shift from freeway expansion to expansion of transit and TDM strategies lowered the incentives for agencies such as Caltrans to attempt to claim credit for their air quality improvements from ITS, it also raised the incentives for transit agencies to claim credit for air quality benefits from their ITS programs. For this reason, we see CMAQ funding used more liberally for incorporating ITS into buses and stations, particularly in LA County. For example, CMAQ funding, distributed to a number of individual transit agencies, is supporting the deployment of the universal fare system, comprising 12 CMAQ projects in the FY 2004/5 to 2009/10 regional transportation improvement program.

Where information provided through ITS could be used to support transportation demand management, it would also be considered as a benefit to air quality. Earlier TDM strategies were focused on workplaces, with the majority of the responsibility placed on large public and private employers who had to put programs into place to increase the average vehicle ridership or occupancy of their employees' commute trips. Yet, there has been a shift away from workplace-based efforts to reduce employee VMT, toward using information, directly to the traveler, to influence mode choice. As noted in the 2003 Air Quality Management Plan, “one of the reasons individuals choose to drive to a particular destination, often alone, is that they may lack convenient access to information about alternative modes to travel” (South Coast Air Quality Management District 2003, p 22). Therefore, ITS applications such as online transit trip planning, CommuteSmart.info for multi-modal traveler information, and RideMatch.info for carpool and vanpool matching, have emerged as some of the more innovative examples of IIDAPT in the Los Angeles region.

- Assembling the case for ITS
Therefore, the shift in transportation policy from freeway expansion to transit and TDM strategies, would underscore the perception of freeway projects (ITS or otherwise) as not beneficial to air quality, and bolster support for ITS used for transit and TDM as viable air quality strategies. As described above, this would affect the incentives for agencies attempting (or not) to assert that their ITS programs have air quality benefits. However, another issue, is whether agencies, once they decide that they want to take credit for air quality benefits of ITS, can actually “make the case” for those benefits. This leads us to consider the role of assessment in innovating with ITS for air quality purposes.

Some interviewees in Los Angeles expressed the opinion that the regulatory regime for transportation conformity was too restrictive to use ITS as an air quality mitigation tool. In particular, they pointed to the fact that the modeling requirements were those mandated by Congress – “we model not because the model knows, necessarily, but because Congress has mandated the model” (SCAG interview, 2005). They felt restricted by both the demand models, which do not effectively incorporate operational effects such as ITS, and the emissions models, which use set, standard drive cycles, meaning that changes to the drive cycle that result from ITS are not accurately reflected in the models. As a result, according to a transportation planner for ITS in the Southern California Association of Governments (SCAG), “we have a very difficult time assembling the case [for ITS] – through traditional means and through legally required means – to make that case with significant members of the environmental community” (SCAG interview, 2005). Therefore, in Los Angeles, particularly those at SCAG felt, that they cannot justify using ITS in this current framework, even though they believe that ITS deployments in Los Angeles have indeed had important air quality benefits. This above discussion primarily refers to claiming credit for ITS when used as a TCM, where the air quality benefits are calculated with the regional transportation models and emissions models.

The so-called “off-modal” evaluation methodology for CMAQ projects in Los Angeles also reinforces the difficulties in “proving” the air quality benefits of ITS. In fact, the methodology for measuring the emission reductions from improvements to signal timing, actually reduces emissions reduction by half, noting that “initial speed improvements decline to zero improvement by the end of the effectiveness period” (California Air Resources Board 2005, p 27). Therefore, a signal improvement project in Los Angeles would receive half of the air quality credit as an identical project in Houston, solely due to differences in the methods used to calculate emission reductions.

Assessment can have a major impact, not only on the further adaptation of innovations, but in being able to undertake an innovation in the first place. However, in addition to this, consider the influence of a larger number of powerful agencies for air quality. Again, Los Angeles is unique in having a strong regional body for air quality management. Some observers have

269 The author interpreted “significant members of the environmental community” to refer to “important” environmental non-governmental organizations, as well as air quality agencies such as CARB and EPA, which were mentioned elsewhere in the interview.

270 As described in Chapter 5, “off-modal” refers to calculations that are not incorporated in the regional transportation model. For example, it could include an intersection improvement, the scale of which may be to small to measure the impact on a regional scale.
highlighted the influence that the South Coast Air Quality Management District (SCAQMD, or AQMD) had over air quality, energy, transportation, land use, and other key decisions in the region.

"By the end of the decade, the twelve-member AQMD board had emerged as almost a de facto regional governing body for the multicounty megalopolis of Los Angeles. A substantial administrative apparatus had grown up employing more than 1,000 staff with a $100 million plus annual operating budget, in a handsome, new, Diamond Bar headquarters, with enormous authority" (Mazmanian 1999, p 87).

As a result, if the transportation agencies could not make the case for the air quality benefits of an ITS project, and there was no support from either CARB or SCAQMD, there would be little prospect for incorporating it as a TCM. In the interviews and site visits, it was also clear that there were several examples of ITS having – or perceived to have – important air quality benefits, without either taking credit for those air quality benefits in air quality plans, or seeking funding through the CMAQ program. It also reaffirms that ITS is undertaken primarily as a tool to mitigate congestion in the Los Angeles case.

"[With] ITS, while they do have those [air quality] benefits, and we would like to claim more credit and push more research in that area because we think it does help, the reality is that many of these programs, we are doing these because we need them in order for the system to function efficiently.” (SCAG interview, 2005)

Taking a specific example, the Department of Transportation for the City of Los Angeles represents an interesting case of an attempt at IIDAPT that was unsuccessful in garnering support from air quality agencies. A few years before the development of the Adaptive Traffic Control System (ATCS), LA DOT had developed a proposal to install carbon monoxide (CO) sensors in the traffic signal cabinets at certain intersections, in order to use the communications infrastructure to retrieve real-time information on concentration levels of carbon monoxide. Using information on air quality levels, and mapping areas of high CO concentrations to heavy traffic on their geographic information system (GIS), engineers could make signal timing improvements based on the CO levels at intersections. As discussed in Chapter 5, this proposal for funding was not accepted by SCAQMD.

Apparently, the emission benefits of ITS, at least as a traffic flow improvement measure, have not convinced air quality planners to the extent as it has in other regions such as Houston. According to Caltrans:

"The greatest amount of pollution comes from individual cars... and ITS plays a role in directing that. But, from CARB’s standpoint, they are thinking about the entire state picture – so they focus on improving cars’ performance” (Caltrans interview, 2005).

Therefore, one argument for the relative lack of acceptance of the air quality improvements from ITS-based traffic flow improvements is that they seek out measures with greater impact by reducing emissions through cleaner vehicles and fuels. However, another explanation lies in

271 Again, California is unique in the US in that it is authorized to set more stringent emissions standards (although not fuel economy) for the vehicles within the state.
the view of induced demand taken by the air quality agencies. One of the transportation planners for ITS at SCAG pushes this second point, suggesting that both state and federal environmental agencies have created barriers to using ITS-based improvements to traffic flows as a strategy for air quality improvements.

"CARB and EPA have been somewhat didactic in their view on operational changes – that operational changes are capacity inducing, that [their emissions improvements] can't be documented – so we have some people who are in the bureaucracy itself that are antipathetic towards ITS and operational improvements as a means of air quality benefits" (SCAG interview, 2005).

Specifically, because of the greater number of "regulating" agencies, with not only CARB, a powerful state-level actor in air quality management, but also the air quality management districts, such as SCAQMD, approval for innovations for ITS and air quality requires the approval of multiple layers of government. ITS projects for air quality must pass these numerous filters for final approval, so the likelihood of successfully using ITS as TCMs, or funding ITS with CMAQ money, is lower in the Los Angeles region.

- A diverse region

Although we have discussed the case of Los Angeles as a region, there are important differences from county to county in their use of ITS for air quality. Indeed, in Los Angeles, the large number of agencies, may have contributed to the range in ITS applications that are for air quality. This range is also made possible by the large sum of CMAQ funding that is available in the region, and the decentralized process by which those funds are programmed. In particular, for the use of CMAQ funds for ITS, the county to county differences are evident. San Bernardino, a rapidly growing inland county, used the funding for a large number of signal coordination, connection, and synchronization efforts. Los Angeles County, on the other hand, used CMAQ for ITS nearly exclusively in the area of transit improvements, including the universal fare payment, communications equipments and AVL. Orange County, which has used its CMAQ funding heavily for transit capital projects, had one ITS and air quality measure – database development for rideshare matching. Therefore, our earlier discussion of the shift in transportation and air quality policy away from freeway and toward transit and TDM, must also be tempered by the fact that this is by no means a homogenous region. San Bernardino and Riverside are facing major population growth pressure, and are not built out to the extent that counties such as Orange and Los Angeles are. Therefore, where possible, they will push more for ITS that can improve traffic flow and air quality, compared to their neighboring counties to the west.

6.2.2.4 Conclusion

For the case of Los Angeles, the conditions also closely predicted the actual IIDAPT levels. Although the average levels of IIDAPT are not as high as in Houston, there is a much larger range, meaning that LA has experimented with ITS as a measure to improve air quality through a variety of different approaches. The conditions that might have prevented LA from having higher levels of IIDAPT, as predicted by the theory, was the difficulty faced in cooperation. Not
only is there a larger number of agencies, but air quality agencies are significantly stronger and more directly involved in determining what transportation-based emissions reduction measures will be implemented. Moreover, the views of ITS-based traffic flow improvements, particularly for freeways, by the air quality agencies, has not always been positive. However, this large number of agencies may also have generated room for more variety of experimentation with ITS for air quality. This hypothesis will be explored below in Section 6.3.

As with the case of Houston, additional explanatory power can be derived from the theoretical framework by looking at the interaction between the local context of transportation planning, decisionmaking and investments, and mutual benefits (see Figure 6-1). Because of the fundamental shift away from increasing capacity for private automobiles, as a new central tenet in transportation and air quality planning in LA, we should not be surprised that organizations have not found it in their best interests to support freeway ITS as a measure to improve air quality, while transit ITS has been incorporated as an important air quality measure. LA has pursued multiple lines of innovation in using ITS for transit and demand management as a measure to support air quality improvements. Yet, these same trends mean that other innovations, such as traffic signalization, freeway management, and freeway information strategies, may have not been deployed with air quality goals as broadly as might have otherwise been possible.
6.2.3 Boston

On the surface, Boston presents probably the most difficult of our five cases in terms of predicting IIDAPT outcomes – precisely because it is a case in the middle. It does not have the extreme or severe non-attainment status, such as Los Angeles and Houston, yet neither is it in attainment with air quality standards, such as Orlando and Tulsa. It has congestion, but ranks only as the 21st most congested city.\textsuperscript{272} Deployment of ITS is not high, but is not terribly low either.

6.2.3.1 Conditions and Predicted IIDAPT in Boston

With a 1-hour ozone non-attainment designation of “only” serious, Boston has not had the same pressures to reduce emissions from mobile sources as have cities such as Los Angeles and Houston. Indeed, with the number of ozone 1-hour exceedances dropping steadily since the 1990s – and only one exceedance in both 2003 and 2004 – air quality itself has not been a highly salient issue in the Boston region. Congestion and other transportation issues, on the other hand, have been more visible, particularly nearing completion of the Central Artery/Tunnel Project, or Big Dig.\textsuperscript{273,274} This might indicate mutual benefits to be gained from using the issue of air quality to promote greater use of ITS for congestion mitigation. Also, given the funding pressures that have been generated by the Big Dig, one would expect ITS to be an appealing, low-cost investment alternative to improve congestion both around the Big Dig, and in other parts of the system.

In terms of internal resources, the staff to the MPO, the Central Transportation Planning Staff (CTPS), has approximately 60 analysts and planners. Most of these are transportation planners and traffic and transit analysis, with fewer planners and analysts in the area of air quality. In terms of dedicated resources, because of the designation of serious non-attainment, Boston does not receive substantial levels of CMAQ funding, and can only fund a dozen or so projects during a TIP cycle, even when many of those projects are bicycle projects that are generally cheaper than other TCMs. This moderate level of internal and dedicated resources for improving air quality through local transportation measures, indicates a lower capability to pursue innovation with ITS for air quality purposes. Because of lower levels of CMAQ funding, we would also not anticipate the same “pursuit” of CMAQ funds that is often seen in other cities where CMAQ is a relatively more abundant source of funding for many non-highway capital and operations projects.

The number of agencies involved is relatively more contained than other cities. For example, the Boston Region MPO members include seven agencies, seven municipalities (the cities of Boston, 272 With a Travel Time Index of 1.34, Boston is closer to Orlando (1.30) than to Houston (1.42). Schrank, D. and T. Lomax (2005). The 2005 Urban Mobility Report. College Station, TX, Texas Transportation Institute.
273 Boston has a travel time index of 1.34 for congestion.
274 We will use the terms Central Artery/Tunnel (CA/T) and the more common “Big Dig” interchangeably.
Everett, Newton and Salem, and the towns of Bedford, Hopkinton and Framingham)\textsuperscript{275} and a public advisory council (the Regional Transportation Advisory Council). The MBTA is the service provider of all major transit services in the Boston area. Therefore, cooperation would not be as difficult to undertake as in more complex metropolitan areas.

Finally, there is a low level of new information regarding the air quality impacts of ITS. Because there is no widely accepted methodology or approach for measuring the emission reductions from such projects, most of the information developed has been done sporadically. For the most recent CMAQ-funded projects, all calculations were done off-model, with the exception of the Burgin Parkway project. There also does not seem to be a push from either within government or other stakeholders to more rigorously assess the possible air quality impacts of ITS from traffic flow improvements. This could be explained in part by the moderate level of deployment of ITS in Boston, and the focus of public opinion on the Big Dig and the completion of the transit agreements. But, in general, there appears to be a lack of interest regarding how ITS can either reduce or increase emissions.

With these factors in mind, we would expect a much lower level of IIDAPT for ITS and air quality than seen in Los Angeles or Houston. With a lower problem severity, and smaller pot of CMAQ funds to access for ITS projects, there would be much less motivation to link the two goals areas of mobility and air quality through strategic deployment of ITS than was the case for Los Angeles and Houston. Also, the organizational capacity to link ITS and its air quality benefits is more limited, with fewer air quality specialists on the staff of the MPO to analyze the possible air quality impacts of ITS, and fewer resources (specifically, CMAQ funds) with which to experiment with ITS as a measure for reducing emissions. Therefore, as seen in Table 6-12 below, the predicted IIDAPT levels are medium.

6.2.3.2 Actual IIDAPT in Boston

Indeed, the site visit, interviews and review of analyses and planning documents indicated that IIDAPT was moderate. In terms of range, there were cases of IIDAPT for four out of the ten application areas (see Table 6-10). The levels of innovativeness and cooperation, however, were medium to low.

\textsuperscript{275} The City of Boston is the only permanent municipal member, while the other six representative municipalities are elected each year.
Table 6-10 IIDAPT level and range for Boston

<table>
<thead>
<tr>
<th>ITS application areas</th>
<th>Representative technology</th>
<th>IIDAPT scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arterial traffic flow improvements</td>
<td>City of Boston TMC</td>
<td>2.5</td>
</tr>
<tr>
<td>Freeway management strategies</td>
<td>Traffic Operations Center</td>
<td>3</td>
</tr>
<tr>
<td>Freeway traveler information</td>
<td>SmarTraveler</td>
<td>N/A</td>
</tr>
<tr>
<td>Transit information</td>
<td>–</td>
<td>N/A</td>
</tr>
<tr>
<td>Multi-modal information</td>
<td>–</td>
<td>N/A</td>
</tr>
<tr>
<td>Transit operational improvements</td>
<td>Signal priority</td>
<td>4</td>
</tr>
<tr>
<td>Transit fare payment systems</td>
<td>CharlieTicket / CharlieCard</td>
<td>N/A</td>
</tr>
<tr>
<td>Rideshare support</td>
<td>Online rideshare matching</td>
<td>2</td>
</tr>
<tr>
<td>Demand management/pricing</td>
<td>–</td>
<td>N/A</td>
</tr>
<tr>
<td>Other applications</td>
<td>–</td>
<td>N/A</td>
</tr>
</tbody>
</table>

Average level (0-6) 2.9  
Range of IIDAPT (0-10) 4

While the average level and range are in accordance with what our theory would have predicted, the intensity of use of ITS for air quality improvements is lower than expected (as seen in Table 6-11).

Table 6-11 Measures of IIDAPT for Boston

<table>
<thead>
<tr>
<th>IIDAPT measures</th>
<th>Aggregate level</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intensity (share of 2006-8 CMAQ projects)</td>
<td>1/13 8%</td>
<td></td>
</tr>
<tr>
<td>Intensity (share of 2006-8 CMAQ funding)</td>
<td>$1.15 M / $47.17 M 2%</td>
<td></td>
</tr>
<tr>
<td>Intensity (share of 1996-8 CMAQ projects)</td>
<td>3/18 17%</td>
<td></td>
</tr>
<tr>
<td>Intensity (share of current TCM projects)</td>
<td>2/10 20%</td>
<td></td>
</tr>
</tbody>
</table>

For example, with current CMAQ funding for fiscal years 2006-2008, there is only one ITS measure – expanded staffing of the City of Boston’s Traffic Management Center. However, this is one of the smallest programs in terms of funding. ITS only represents 2% of all CMAQ funding, with little over one million dollars of these federal dollars. Interestingly, this contrasts with earlier years where CMAQ funding was used more widely for traffic flow improvement projects such as incident management, motorist assistance, and the traffic operations center. Indeed, these projects also provided a nontrivial share of the emissions reductions from all CMAQ projects (see Chapter 5). Early IIDAPT was more focused on freeway management, incident management, and motorist assistant patrol, for example, building on the Traffic Operations Center as laid out in the 1994 ITS Strategic Plan for Boston. 276 However, as progress was slow on the deployment of the Strategic Plan, there was a shift in CMAQ funding toward

more scaled-down and short-term projects.\textsuperscript{277} Compared to the mid-1990s, when CMAQ was used more liberally for ITS-based traffic flow improvements, there is currently little to no usage of ITS in this manner, with the exception of the City of Boston’s TCM. This decline in the use of ITS for emission mitigation is somewhat counterintuitive, as one might have considered ITS as an attractive, low-cost means to mitigate congestion in other parts of the Boston region, particularly given the financial constraints caused by the Big Dig.

For assessing the current level of participation of ITS as a measure to improve air quality, we look beyond CMAQ, to the transportation control measures, using as a reference the 2005 Transit Commitments Status Report. Including the Urban Ring, expansion of Silver Line Service, and Signal Prioritization – all of which would rely heavily on elements such as AVL, transit signal priority, in-vehicle communication units and computer-aided dispatch, in-vehicle public announcement/variable message systems, and electronic fare payment – we find that three of the ten transit commitments in the report are ITS-based or ITS-enhanced measures.\textsuperscript{278} However, we do not include the Urban Ring in our measure of IIDAPT intensity, as this project is still in the early stages of environmental review. Therefore, for the intensity of use of ITS for air quality purposes, we therefore find an IIDAPT intensity of 20% for these SIP transit commitments.

Therefore, perhaps the more important issue than the level and intensity of IIDAPT in Boston, is the variation across modes, and how this has changed over the years. More recently, the projects that use ITS as a supporting measure for improving air quality are predominantly transit projects, whereas there has been little effort to use ITS-based traffic flow improvements as air quality measures.

\textit{6.2.3.3 Comparison and Discussion}

The conditions in Boston would predict a medium level of IIDAPT in Boston. Indeed, that is what was observed. Therefore, our theory also worked well for the case of Boston in terms of overall IIDAPT levels. Yet, given that the congestion problem is comparatively more important than the air quality problem, we might have expected more focus on ITS-based traffic management and traffic flow improvements for air quality. While we did see some evidence of this in early CMAQ funding patterns, more recently the majority of IIDAPT has been oriented toward improving transit service, specifically, bus service, as transportation control measures.

\textsuperscript{277} Indeed, although CMAQ funding was used for the Traffic Operations Center, and emissions estimates were based upon for the full deployment of the year 2000 plan (213 kg/day for VOC, and 32 kg/day for NOx), full deployment was never actually reached.

\textsuperscript{278} We could also consider the Orange Line Improvements, which are primarily improvements in signalization for the Orange Line trains. However, because rail communications are not typically considered part of the ITS taxonomy, we will not include it in our measure of intensity.
Table 6-12 Comparison of predicted and actual outcomes in Boston

<table>
<thead>
<tr>
<th>Theoretical Outcomes</th>
<th>Actual Outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Seven conditions from theory</strong></td>
<td><strong>“Predicted” outcomes based on seven conditions</strong></td>
</tr>
<tr>
<td>1. Problem severity – med</td>
<td>Summary: MEDIUM</td>
</tr>
<tr>
<td>2. Internal resources – med</td>
<td>• Innovation – med</td>
</tr>
<tr>
<td>3. Dedicated resources – med</td>
<td>• Cooperation – med</td>
</tr>
<tr>
<td>4. Cost - low</td>
<td>• Assessment – low</td>
</tr>
<tr>
<td>5. Mutual benefits – med</td>
<td>• Adaptation – low</td>
</tr>
<tr>
<td>6. Number of agencies – med</td>
<td></td>
</tr>
<tr>
<td>7. New information – low</td>
<td></td>
</tr>
</tbody>
</table>

*Funding pressures and the CMAQ pot*

Looking at the CMAQ funding category, we ask whether this has served either as an enabler or motivator of IIDAPT for ITS and air quality, as theory would predict. One interviewee suggested that because the “demand [for funding] is so great, for traditional transportation projects, that if there wasn’t the CMAQ program or enhancement categories, [ITS projects] would be a lower priority, it wouldn’t be a high priority to fund them” (MBTA interview, 2005). From this statement, it might seem that CMAQ has been an important source of funding for projects such as bicycle and pedestrian facilities, demand management projects, ITS operational improvements and other enhancements and operational improvements. Yet, in the case of Boston, even the more “protected” CMAQ funding was subject to major inroads by traditional transportation projects, being used for projects that at times seem to barely meet the requirements for non-SOV increasing projects, pushing the limits of the category of traffic flow.
improvements. Indeed, in the TIP for fiscal years 2004-2006, $13.7 million of CMAQ funds were actually directly designated to the CA/T project, with only $2 million going to projects such as demand management programs and transit shuttles. A more recent example is the Burgin Parkway project, a major interchange reconstruction project south of Boston in Quincy. Although ultimately supporting the project and its inclusion in the TIP, several members of the Regional Transportation Advisory Council expressed strong concerns regarding the selection process for this project, suggesting that CMAQ eligibility and project readiness had “taken precedence over its evaluation ratings.” This project represents $14.4 million of the $37.3 million in CMAQ funds to the region.

As a result of the funding pressures created by the Central Artery/Tunnel project, Boston exemplifies the situation that occurs when there is little “slack” in resources, even where slack has intentionally been created. It also represents the situation in which the problem – air quality – is not severe enough to serve as a check on the possible misuse of dedicated CMAQ funds. Indeed, because Boston was expecting to come into attainment in large part due to reduction of NOx from upwind sources in New York, New Jersey, Connecticut, and other states, the air quality agencies did not have the incentive to push the use of CMAQ funds toward transportation control measures or other CMAQ-eligible programs for reducing emissions from mobile sources.

- **Modifying the Transit Commitments**

The other story is that of the transit commitments. While this apparent misuse of CMAQ funds has largely passed by the public without much notice, the SIP transit agreements that were established as a condition of the Conservation Law Foundation (CLF) agreeing not to litigate the CA/T, have been a source of continuous controversy. Boston’s history of transportation control measures for air quality has followed a slightly different path than Houston or Los Angeles. While for Los Angeles and Houston, the substitution of TCMs is basically a matter of negotiation with the state air agency and EPA, in the case of Boston, the substitution of TCMs (particularly, the CA/T transit agreements) is an issue of local negotiation with interested and often highly mobilized stakeholders. While air quality benefits are part of the issue, and indeed were the basis for the original threats of litigation (and for later instances of litigation), it is not the most important consideration, at least for the proponents of the measures contained in the transit agreements. Their concern is based in securing the transit benefits that were promised to them as a condition of moving forward with the Big Dig. The transit agreements for air quality mitigation, necessary to secure CLF’s support of the Central Artery/Tunnel project, have thus shaped many transportation decisions, and as a consequence, important ITS decisions.

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279 Boston is not the only city that has included traffic flow improvement projects that could be almost considered capacity-expansion. Indeed, some ITS improvements could fall within this category. For example, critics in Houston consider many of the CMAQ-funded ITS-based traffic flow improvement projects to be merely part of larger highway capacity expansions.

280 We use this term with respect to the question of whether the use of these funds has complied with the congressional intent of the establishment of the CMAQ program.
A concrete example of the interplay between air quality and ITS in the CA/T transit agreements, is the restoration of Arborway trolley service to the Jamaica Plain neighborhood. As discussed in Chapter 5, the EOT and MBTA have attempted to remove this project from the list of the transit commitments, substituting for it with projects promising higher air quality benefits and lower costs. In the meantime, new articulated buses have been introduced along bus route 39 (in the fall of 2003), which serves Jamaica Plain from Forest Hills T-station to Copley and Back Bay station. The MBTA has attempted to improve schedule adherence and reliability on this route, the most heavily utilized bus route in the MBTA system. One of the proposed projects for 2006, is a planning study for the Arborway corridor, to identify transit signal priority strategies that could further improve service of the 39 bus, and estimate the impacts on both bus passengers and general traffic. This system would use GPS and in-vehicle units to automatically request priority from the MBTA Bus Control Center, if the bus is behind schedule by a designated amount of time.

By analyzing the interests of the different organizations regarding the alternatives for the Arborway corridor, we will see that there are strong mutual benefits from the use of transit ITS in response to the CA/T transit mitigation agreements. Our purpose here is not to evaluate which system would better improve both mobility and air quality. Instead, we want to understand the interests of the various organizations and actors, and assess how the interplay of these interests may align in ways that promote greater usage of ITS as a way to generate air quality benefits.

The key player is the MBTA, which has been delaying the Arborway trolley restoration on the grounds that it is infeasible, and attempting to compensate with other forms of transit service using newer and lower-emitting articulated CNG buses on the 39 bus route and equipping those buses with advanced technology with the possibility of signal priority in the future. The MBTA essentially wants flexibility in revisiting and substituting for the original transit agreements, and in developing a new plan that according the MBTA’s estimates “costs less than the state would have to pay to fulfill the original agreement, serves almost twice the number of commuters, and has double the air quality benefits.” In addition, the MBTA has an interest in further promoting the shift toward rapid transit services that utilize ITS – having already wagered on the viability of BRT-type services through its highly publicized deployment of the Silver Line. Its commitment toward ITS-type systems is also reflected in the MBTA’s current emphasis on its deployment of automated fare collection (the CharlieTicket and CharlieCard) and expansion/interconnection of the Silver Line. Even for longer-term projects that are still in the early planning stages, such as the Urban Ring, the concept is also a BRT-type service. Therefore, the MBTA has a incentive to continue to argue and lobby for BRT-type services, rather than promote trolley services. While a ITS-enhanced service for the 39 bus would fit in well with the MBTA’s general thrust toward both improved bus service, the agency also walks a fine line in that they cannot appear to be blatantly reneging on earlier commitments. The

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281 Signal priority is already in place for some intersections along the Silver Line.
283 At the 11th Annual Meeting of ITS Massachusetts in May 2006, the emphasis on this new initiative was underscored by the title of the presentation, “The Year of Charlie,” given by Joshua Martiesian of the MBTA.
MBTA’s preferences also align with the interests of the state-level Executive Office of Transportation (EOT), which has advocated a move toward “objective criteria” in evaluating transit and transportation incentives.\(^{284}\) The EOT considers transit and other investments from a broader systems and forward-looking perspective, but also with a tendency not to defer as much to earlier commitments made by previous administrations to specific communities.

Another important actor in the case of the Arborway trolley restoration versus BRT-type service, is the Boston Transportation Department. Their primary concerns arise from the potential traffic impacts from restoring trolley services to the corridor, and maintaining the corridor’s “existing functions” of emergency vehicle access, deliveries to local businesses, parking, traffic circulation and pedestrian and bicycle safety (Boston Transportation Department 2003, p 33). Therefore, BTD has an incentive to work with the MBTA on signal priority along the corridor – rather than the other, possibly more complex traffic mitigation measures that might be necessary in order to maintain general traffic flows and vehicle access with a restored trolley line – even though the City is generally extremely cautious about expanding transit priority because of possible impacts on general traffic.

In addition to the governmental agencies involved in the trolley restoration process, are, of course, the stakeholders involved in the process. The Conservation Law Foundation (CLF) – as the original architect of the CA/T transit mitigation commitments – is the most visible actor. CLF has continued to threaten the aforementioned agencies and others in an attempt to keep the commitments on track.\(^{285}\) Other local groups that have organized in response to the transit commitments are represented by the Arborway Committee (for trolley restoration) and Better Transit Without Trolleys (BTWT) (against trolley restoration and for substitution by better bus service, as the name suggests).\(^{286}\) While the Arborway Committee and CLF continue to press of the original trolley agreements, BTWT advocates an approach more congruent with that of the MBTA. Although BTWT suggests a broad range of service improvements, many of their recommendations include the use of ITS.

Finally, the Department of Environmental Protection (DEP) has had the responsibility of determining whether the trolley restoration is, in fact, infeasible, which would essentially release the MBTA from their legal obligation to implement this project. DEP has the legal commitment to follow-up on the implementation of the SIP transit agreements. But, from the viewpoint of air quality, demonstrating actual attainment of the air quality standards depends more on reduction of NOx from upwind industrial sources and from the introduction of cleaner vehicles into the fleet, than it depends on any TCM-type projects.

Therefore, the use of ITS to support an improved service for the route 39 bus provides an interesting example of the proposed use of ITS to essentially shelve the commitment to restore the Arborway trolley service. We are not casting judgment here on which project would be

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\(^{284}\) In Chapter 5, we discuss this concept of “objective criteria.”

\(^{285}\) In somewhat ironic twist, in the most recent litigation, the second defendant in the lawsuit was former CLF-president Douglas Foy, in his official capacity as Secretary of the Office for Commonwealth Development.

\(^{286}\) The positions of these two organizations can be reviewed at their respective websites: The Arborway Committee at www.arborway.net/lrv/ and Better Transit Without Trolleys at www.btwt.org. Last accessed March 29, 2006.
preferable either in terms of air quality, mobility or even environmental justice. Instead, we are explaining the factors that determine how interests line up in favor of one option as opposed to another. Given how the interests of the key organizations are lined up in favor of a more ITS-intensive route 39 bus, instead of the trolley restoration, trolley restoration would seem unlikely.

- Making the case for the Big Dig

Finally, we review the use of ITS for better management of highway and arterials traffic flows. As suggested by the ITS indicators, the Boston Region has ranked only medium in the overall use of ITS. The site visit also revealed that ITS deployment has been slow for freeway and arterial management, and that there has been very limited use of ITS for improving air quality through traffic flow improvements. Early CMAQ funding was used for applications such as incident management and Traffic Operations Centers (typically referred to now as Transportation Management Centers). However, the more recent trend has been to include traffic improvements from physical infrastructure improvements, not from better operations and management. Although one might suggest funding issues, some interviewees stated that funding was not a reason for the low levels of ITS implementation in Boston.

Returning again to the issue of the Big Dig, and its impacts on transportation policy in Boston, we can suggest another possible reason, again, looking at the interests of the key actors. Given the conflict and controversy that the CA/T and its rising costs have created, MassPike and MassHighway both have vested interests in having the public and the federal government see the project as a success. ITS elements are heavily incorporated into the CA/T to ensure its effective operation once fully complete. There is clearly a "buy-in" or recognition of the value of ITS in ensuring the effective capacity of a major highway. Therefore, it appears inconsistent that ITS has not been more widely deployed throughout the rest of the transportation network as a low cost option to manage congestion. Indeed, 2004 data for deployment indicated that only 20% of freeway miles in the Boston area had real-time traffic data collection technologies, compared to the national average of 35%. With the agencies locked into a massive traditional infrastructure capacity expansion, they might not have had a strong interest in also focusing on ITS as a possible alternative to improve effective capacity and increase the reliability of travel time at a lower cost.

6.2.3.4 Conclusion

These two examples provide an interesting contrast between the use of ITS to support air quality improvements through better transportation operations and management – both for transit and traffic – versus more traditional capital infrastructure investments. The agencies responsible for implementing the transit air quality commitments have an interest in demonstrating the viability of ITS as a lower-cost investment to expand and improve transit service in the region, rather than what they consider to be infeasible capital-intensive transit projects. On the traffic side, the opposite has occurred. There seems to be little effort in stressing the use of ITS as a lower-cost congestion mitigation tool for freeway and arterial traffic. This may be due to early problems in the deployment of the elements of the 1994 Strategic Plan, as legacy issues and the resolution of technical problems with some of the early deployments would hinder later deployments, and
make air quality planners more wary in incorporating them into CMAQ funding or as TCMs. Yet, it could also reflect an interest on the part of MassHighway, the EOT, and MassPort in highlighting the role of ITS as an important enhancement for new capacity projects (such as the CA/T), but not as an alternative to capacity expansion. Again, mutual interests, defined and shaped by the local context and the history of transportation investments and decisions, have a major impact on IIDAPT outcomes.
6.2.4 Orlando

Orlando was chosen as a case study because of the absence of major air quality problems, but very high levels of ITS deployment. It was intended to provide a point of comparison with Houston, in that Orlando has similarly high levels of ITS deployment, indeed, among the highest in the US, albeit scaled to a much smaller metropolitan area (for example, fewer highway and arterial lanes miles, signalized intersections, etc). It can also be juxtaposed with the case of Tulsa, which also was in attainment with the 1-hour ozone standard, but had some of the lowest levels of ITS deployment in the nation. Therefore, the underlying question for the case of Orlando, was whether in a city with substantial experience with advanced ITS deployment, organizations would also experiment with ITS for the purposes of reducing emissions, in the absence of a major air quality problem.

6.2.4.1 Conditions and Predicted IIDAPT in Orlando

With its overall low level of emissions and atmospheric conditions that are favorable to maintaining good air quality, Orlando does not have serious air quality problems. The area has been in attainment of ozone, and does not appear to be in danger of going out of attainment in the near future. The MPO, Metroplan Orlando, has worked to keep the discussion on air quality issues active, and has looked toward Atlanta as an example of the failure to address air quality problems and the risks to transportation investments that situation can pose. However, without the regulatory requirements of conformity and therefore having to identify local transportation control measures, there are no concrete mutual benefits for agencies to couple ITS with air quality benefits.

As a small-medium size metropolitan area, Orlando has a moderate number of agencies actively involved in ITS deployment. In addition to the state DOT, transit agency, the City of Orlando and three counties (but specifically, Orange and Seminole County) deploy and operate ITS technologies. The MPO, Metroplan Orlando, has also become involved in fostering not only metropolitan level planning, but also regional transportation operations. Yet, the number of agencies is still manageable from the viewpoint of cooperation. Interviewees at the Orlando-Orange County Expressway Authority (OOCEA), referring to their ability to coordinate actions among various agencies to experiment with technologies such as intermodal Smart Cards, suggested that:

"Orlando is unique in its size. It has the resources to do these things, but we don’t have the conglomeration of agencies and jurisdictions that some of the larger cities do" (OOCEA interview, 2005)

This also brings us to the issue of internal resources. The staff of Metroplan is of small to moderate size, with approximately 20 full-time staff members. Although no conformity demonstration was actually required of Orlando, the long-range transportation plan does include

\(^{287}\) Specifically, the quote was in reference to the "ORANGES" demonstration project to test the technical and organizational viability of an intermodal smart card for payment of expressway tolls, parking, and transit fares.
an assessment of the impact of the plan on regional emissions. This points to the presence of MPO staff capable of doing some of the emissions modeling, even if not with the depth that would be required for a full transportation conformity analyses. For ITS deployment, there is a high level of internal resources for most of the major agencies, including the city and counties. Seminole County, for example, undertook many of their ITS activities using in-house staff rather than contracting out, allowing them to develop a substantial knowledge base and experience with ITS.

The area had a moderate level of dedicated resources for ITS, by creating set-asides from the STP funding category for ITS and other non-highway projects. Orlando also has dedicated resources for ITS deployments through federal grants, for deployments such as iFlorida and for earlier field operational tests such as TravTek. Yet, because the Orlando was in attainment, they received no CMAQ funding. Therefore, dedicated resources for ITS projects that could be shown to have an air quality benefit, were nonexistent.

There have been numerous studies looking at the air quality impacts of ITS deployments in Florida, namely by faculty at the University of Central Florida. In Orlando, there are several faculty from Civil and Environmental Engineering at UCF, who have worked on simulations, modeling and assessments for projects under contract to Florida DOT, OOCEA, and at times to LYNX, the cities and counties. Some of these assessments have included air quality impacts. Researchers from UCF were also responsible for the development of the region’s emissions inventory, as discussed in Chapter 5. Therefore, with new information emerging on the air quality impacts of ITS, we would predict that there would be some adaptation of those deployments.

6.2.4.2 Actual IIDAPT in Orlando

In the absence of a non-attainment designation and CMAQ program funding, the motivation to actively use ITS to meet air quality objectives has been quite limited. Our conditions, looking at Table 6-14, predicted a very low level of IIDAPT. Indeed, what was found was that there was actually no IIDAPT according to our criteria, as shown in Appendix E, and summarized below in Table 6-13.

<table>
<thead>
<tr>
<th>IIDAPT measures</th>
<th>Average level</th>
<th>Range</th>
<th>Intensity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

While there have been some studies of the air quality impacts of Orlando’s ITS deployments – electronic toll collection and in-vehicle navigation – the focus was primarily on mobility improvements, travel time savings, and delay reduction. Air quality impacts, where assessed, were secondary considerations, and there appears to be no real adaptation of those deployments to improve the air quality outcomes of ITS.
6.2.4.3 Comparison and Discussion

The results of the Orlando case study were interesting in that they highlighted that having non-attainment status, or even facing a real possibility of falling into non-attainment (as was the situation with Tulsa) is an important condition for experimentation with ITS for air quality improvements. It answers our question posed earlier: in a city with substantial experience with advanced ITS deployment, would organizations also experiment with ITS for the purposes of reducing emissions, in the absence of a major air quality problem? The answer for Orlando was no. This affirms the central importance of the severity of the problem as a condition leading to innovation. Although Orlando had many of the conditions that could have lead to extensive use of ITS for air quality – ease of cooperation because of a manageable number of agencies, strong internal resources, and dedicated resources for ITS (although not necessarily for air quality purposes) – in the absence of the federal requirements for transportation conformity, no innovation was undertaken for reducing emissions through ITS.

Table 6-14 Comparison of predicted and actual outcomes in Orlando

<table>
<thead>
<tr>
<th>Theoretical Outcomes</th>
<th>Summary: VERY LOW</th>
<th>Actual Outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seven conditions from theory</td>
<td>Predicted outcomes based on seven conditions</td>
<td>Summary: NONE (0)</td>
</tr>
<tr>
<td>1. Problem severity – none</td>
<td>Summary: VERY LOW</td>
<td>Description:</td>
</tr>
<tr>
<td>2. Internal resources – med</td>
<td>Innovation – none</td>
<td>No examples of IIDAPT. Some assessment, but no deployment or adaptation of ITS for air quality purposes.</td>
</tr>
<tr>
<td>3. Dedicated resources – none</td>
<td>Cooperation – low</td>
<td>Quantitative measures:</td>
</tr>
<tr>
<td>4. Cost - low</td>
<td>Assessment – low</td>
<td></td>
</tr>
<tr>
<td>5. Mutual benefits – none</td>
<td>Adaptation – low</td>
<td>• Average level: 0</td>
</tr>
<tr>
<td>6. Number of agencies – med</td>
<td></td>
<td>• Range: 0</td>
</tr>
<tr>
<td>7. New information – med</td>
<td></td>
<td>• Intensity: 0%</td>
</tr>
</tbody>
</table>

Assessments were undertaken for TravTek and E-Pass (described both in Chapter 5 and Chapter 2). However, in the case of TravTek, the focus was more on using Orlando as a test bed for analyzing air quality impacts of an advanced ITS deployment, and did not appear to have the intention of supporting actual decisionmaking in Orlando regarding the broader deployment of those technologies. Not surprisingly, there was no adaptation to this information. The case of E-Pass was different. Measurement of emissions changes from ETC was included as part of a broader study to evaluate the benefits of the deployment of automated vehicle identification for toll payment at the OOCEA plazas and on/off ramps. Although the emissions study by UCF found that NOx increased substantially (34%) due to higher speeds, while HC and CO declined (7%), OOCEA selectively used the results of the study to defend their environmental and air quality record.
6.2.4.4 Conclusion

Therefore, the case of Orlando highlighted that experience in technology deployment, and relatively easy cooperation between a limited number of agencies involved both in transportation and air quality, is not enough. In the absence of a pressing problem, there is no motivation and no mutual benefits to make explicit linkages between ITS deployments and air quality, or to innovate with existing ITS applications for possible emissions reductions. Although this is a straightforward conclusion, it is important to underscore that without the regulatory impetus for addressing a problem, it is difficult to pursue innovative "solutions," even if the institutional capacity to do so is there. Although agencies such as Metroplan are forward-looking, anticipating that continued growth, such as that seen in Atlanta, could lead to future problems in maintaining healthy air, there is no concrete benefit to the transportation agencies for looking for the air quality benefits of ITS, as of yet.
6.2.5 Tulsa

Our final case study city, Tulsa, Oklahoma, was chosen because it was anticipated to have some of the lowest levels of IIDAPT for ITS and air quality. In this manner, it would represent the other end of the spectrum from the case of Los Angeles, a megacity with a history of struggling with both air pollution and congestion.

6.2.5.1 Conditions and Predicted IIDAPT in Tulsa

Tulsa and Orlando were both chosen in part because they are in attainment of all national air quality standards. Tulsa was a slightly different case from Orlando, however, in terms of air quality, because it faced a possible non-attainment designation under the new 8-hour ozone standard coming into effect. Yet, when non-attainment designations for 8-hour ozone were made in June 2005, Tulsa was still in attainment. Congestion levels in Tulsa are among the lowest in the nation (ranking 64 of 85 metropolitan areas surveyed), and the site visit and interviews confirmed the mild congestion in the area. Therefore, problem severity, for both air quality and congestion, is low.

The internal resources of Tulsa were small, not surprising given the size of the metropolitan area, at less than 900,000 residents. In terms of CMAQ funding, the Tulsa metropolitan area did indeed receive some of these funds from ODOT, through the minimum apportionment guaranteed to each state. However, they cannot be considered as dedicated resources in the same manner as CMAQ funds going to non-attainment areas, since they can be used in the same manner as regular Surface Transportation Program (STP) funds, without the requirement to show emissions reductions from these projects.

During the 1990s and until now, there has been no need for Tulsa to meet transportation conformity requirements, given its attainment status. Therefore, the mutual benefits that would result from identifying ITS measures that improve air quality, are theoretically smaller than in non-attainment areas. However, there have been pressures for Tulsa to begin to prepare for a possible non-attainment designation, and the conformity requirements that would result. The number of organizations actively working in the areas of ITS and air quality is small, and is limited to ODEQ, the City of Tulsa (including Tulsa Transit), County of Tulsa, ODOT, and INCOG.

One would expect low levels of innovation, due to the relatively minor air quality problem in Tulsa, the low level of internal resources for transportation operations and air quality management, the lack of dedicated resources for either ITS or transportation projects with a specific focus on air quality, and the low level of experience in innovating with ITS. Of all the cities, Tulsa had the least experience with ITS of our five cities, as shown by its levels of deployment at 10% according to the ITS summary indicator described in Chapter 5. Indeed, as noted by planners at the MPO (Indian Nations Council of Governments, or INCOG), the FHWA has specifically targeted Tulsa as one of the cities that was furthest behind in ITS deployment. Cooperation, on the other hand, would be easier among the limited number of organizations...
working in the area of air quality and transportation. Yet, because Tulsa was not required to meet transportation conformity requirements, including developing transportation control measures for a SIP, one would expect low mutual benefits to be gained from applying ITS to the problem of air quality.

In terms of assessment and adaptation, the conditions would predict very little of either. The case study site visits, interviews and literature did not uncover many studies or evaluations of the air quality impacts of ITS. In part, the low level of ITS deployment can explain this absence of evaluation.

6.2.5.2 Actual IIDAPT in Tulsa

Despite the prediction of very little or no IIDAPT, the site visit uncovered some innovative uses of ITS for air quality purposes. Indeed, some of these programs have been recognized at the national level as innovative approaches for managing ozone – episodic ozone events in particular. Like Orlando, we cannot turn to the state implementation plans (SIPs) or lists of CMAQ-funded projects to locate potential cases of IIDAPT for ITS and air quality. Instead, for Tulsa we will look at two sources of data: the transportation and air quality programs managed by INCOG (Ozone Alert! and RideShare) and the measures included in Tulsa’s Early Action Compact (EAC).

Looking at Table 6-15, we have three technologies that are considered as IIDAPT: (1) traffic signalization projects for the EAC, (2) online matching for RideShare, and (3) the use of variable message signs (VMS) for the Ozone Alert! program.

Table 6-15 IIDAPT level and range in Tulsa

<table>
<thead>
<tr>
<th>ITS application areas</th>
<th>Representative technology</th>
<th>IIDAPT scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arterial traffic flow improvements</td>
<td>EAC signalization</td>
<td>2.5</td>
</tr>
<tr>
<td>Freeway management strategies</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Freeway traveler information</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Transit information</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Multi-modal information</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Transit operational improvements</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Transit fare payment systems</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Rideshare support</td>
<td>Online Match</td>
<td>2</td>
</tr>
<tr>
<td>Demand management/pricing</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Other applications</td>
<td>Ozone Alert! VMS</td>
<td>4.5</td>
</tr>
</tbody>
</table>

Average level (0-6) 3
Range of IIDAPT (0-10) 3

Of these programs, the most innovative was the use of VMS for Ozone Alert! days (scoring 4.5 of 6). First, there was a high level of active cooperation in both the planning and operation of the system. Although this is only an episodic measure, meaning that it does not require daily interaction between agencies, when an Ozone Alert! is called by ODEQ and the Tulsa/County Health Department, there is immediate action from INCOG and from ODOT operators who activate the system for the VMS alerts. This program is also considered innovative – both by
officials in Tulsa, and by the EPA, which highlighted the program\textsuperscript{288} – in that it was the first area in the nation to institute an Ozone Alert! for control of ozone episodes. We add that there is further innovation in that VMS is used to inform drivers of those alerts.

The online matching for RideShare had some novelty in the use of new software available to match riders. RideShare is somewhat different from other cities, in that the main benefits are air quality benefits, with very little focus on the possible congestion benefits. There are no travel time advantages from carpooling, since there are no HOV lanes in the Tulsa area. There is some cooperation, in that INCOG, which manages the program, by its very nature is a cooperative organization.

Although the traffic signalization projects were included in the EAC, they were not highly innovative technologically or in the adaptation to multiple policy goals. But, it was somewhat novel from the viewpoint that these were preventative measures (through the EAC) to avoid going out of attainment by reducing emissions through better operation of the traffic network, rather than physical capital investments (which represented the majority of the other measures in the EAC).

With all three cases of IIDAPT, there has been little assessment and no adaptation of the programs. Evaluation of the traffic signalization improvements were necessary as a condition for inclusion in the EAC. However, the quality of the assessment is uncertain, as the analysis by the consultants was not available for review. On the other hand, according to the case study developed by the EPA, there was work with an advisory group to prepare protocols to quantify the impacts of the Ozone Alert! program.

6.2.5.3 Comparison and Discussion

Tulsa was therefore somewhat of a surprise in terms of expected levels of IIDAPT and actual outcomes. Although Tulsa was designated as attainment in 1991 and remained in attainment even under the 8-hour ozone standard, Tulsa’s limited ITS infrastructure has been used in small-scale but rather innovative ways to also promote air quality goals, such as the use of VMS to post information on Ozone Alert! days.

Table 6-16 Comparison of predicted and actual outcomes in Tulsa

<table>
<thead>
<tr>
<th>Seven conditions from theory</th>
<th>Predicted outcomes based on seven conditions</th>
<th>Actual Outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Problem severity - low</td>
<td>Summary: LOW to MEDIUM</td>
<td>Summary: MEDIUM (2.3)</td>
</tr>
<tr>
<td>2. Internal resources - low</td>
<td>Innovation - low</td>
<td>Average level * range * intensity</td>
</tr>
<tr>
<td>3. Dedicated resources - low</td>
<td>Cooperation - med</td>
<td>3 * 3 * .26 = 2.3</td>
</tr>
<tr>
<td>4. Cost - low</td>
<td>Assessment - low</td>
<td>Description:</td>
</tr>
<tr>
<td>5. Mutual benefits - med</td>
<td>Adaptation - low</td>
<td>Small-scale uses of ITS for air quality purposes, from low IIDAPT (traffic signals, rideshare matching) to high IIDAPT (Ozone Alerts! on VMS)</td>
</tr>
<tr>
<td>6. Number of agencies - low</td>
<td></td>
<td>Quantitative measures:</td>
</tr>
<tr>
<td>7. New information - low</td>
<td></td>
<td>• Average level: 3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Range: 3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Intensity: 26% of measures in Early Action Compact</td>
</tr>
</tbody>
</table>

In Table 6-16, we see that predicted levels of innovation were low, while levels of cooperation were anticipated to be medium. In contrast, higher levels of innovation occurred in Tulsa (with an average IIDAPT level of 3), with the inclusion of traffic signalization improvements in the EAC, online matching for ridesharing, and, the Ozone Alert! program’s use of variable message signs. Above all, the innovativeness of the Ozone Alert! program is substantially higher than one might have expected given the seven conditions. We note that the innovation was more of an operational than a technological innovation. Although variable message signs are not an innovation per se, using VMS to disseminate air quality information and provide information to the public regarding voluntary measures to deal with a limited number of high ozone days, is an innovative approach, and well tailored to the episodic nature of the ozone problem in Tulsa.

Therefore, the fact that Tulsa responded to the issue of air quality by using some ITS applications, while Orlando did not, even through they are both attainment areas, leads one to consider the definition of problem severity in more depth. Tulsa has been in attainment with ozone standards under the 1990 CAAA. However, as the new 8-hour ozone standard was coming into force, Tulsa faced the possibility of falling out of attainment, and thus being subject to the requirements for conformity, which would mean performing conformity analysis on long-range transportation plans, developing mobile source budgets, implementing TCMs, and so on. This caused a brief surge of activity in considering options for reducing transportation-related emissions, modeling air quality trends, and creating the EAC, incorporating a modest number of traffic signalization improvements and other traffic flow improvement projects, as a safeguard against a nonattainment designation. While not highly innovative projects, this example illustrates that the “problem” for the city was not what its air quality monitors were measuring or the health impacts of ozone, but the consequences that falling into a non-attainment category
would have for Tulsa. Indeed, this confirms the use of attainment status as a measure of problem severity.

According to Jerry Lasker, Executive Director of INCOG, during the May 2003 Senate Hearings on the CMAQ program and transportation conformity requirements in TEA-21, there were three reasons why they entered into the EAC in order to avoid a non-attainment designation. First, were concerns about the health impacts of ozone. Second, was the “stigma” associated with being on the “EPA’s Dirty Air List” and the possible economic repercussions. Third, were the difficulties in having to meet the requirements of transportation conformity demonstrations. “We have never done conformity, but we had heard that it takes a lot of work and... it is not any fun” (Government Printing Office 2004). Therefore, this could explain why Tulsa has had some success in small-scale IIDAPT despite the apparent lack of a “problem,” defined narrowly as Tulsa’s attainment designation. This burst of activity mirrors what occurred in 1991, when two exceedances of the 1-hour ozone standard threatened to push Tulsa into non-attainment status. According to Lasker, the Ozone Alert! program was implemented shortly after those exceedances: “we developed a program in 2 weeks ... the fastest I have ever seen Government act” (Government Printing Office 2004).

In the development of the EAC for 8-hour ozone levels, traffic signal system improvements were also used as a near-term measure for air quality improvements. Makler and Howitt suggest that the EAC has served more as a buffer against conformity than actually taking real steps to prepare for conformity, and therefore, if conformity is eventually required, Tulsa will most likely be “comparatively under-prepared” (Makler and Howitt 2003). Nonetheless, given that Tulsa’s ozone problem is not persistent – with only episodic exceedances of the standard – and the growth rates in the city are low, a flexible, voluntary approach taken with consent and support of the business community seems appropriate to Tulsa’s circumstances. Furthermore, as suggested by a planner at ODEQ, in the absence of a major ozone problem it is difficult to justify spending significant resources to both analyze it and solve it (ODEQ interview, 2005).

This definition of Tulsa’s problem also leads us to reconsider the mutual benefits that the agencies in Tulsa can achieve. The mutual benefits in non-attainment cities, particularly in severe or extreme areas, can be often defined, for example, as meeting conformity requirements in the least difficult manner, identifying TCMs that support organizational interests for preferred transportation investments, and accessing CMAQ funding for ITS deployments. In Tulsa, the benefits of programs such as Ozone Alert!, ridesharing, and EAC measures are that they provided a way to avoid the non-attainment designation, and in way that would have relatively low costs and low controversy. For INCOG, they found benefits in avoiding the conformity process that would have significantly increased their administrative burden. As a small MPO, they did not feel prepared to take on the requirements of transportation conformity. In fact, interviewees from INCOG stated that they would prefer to say in attainment, even if it meant...

289 Although it may seem unusual that a representative from Tulsa would appear at the Senate Hearings on transportation conformity and CMAQ (and not, say, representatives from California, Texas or New York), can be explained by the fact that the Chairman of the Committee on Environment and Public Works is James M. Inhofe, Senator from Oklahoma (and from Tulsa).
giving up increased funding possibilities through CMAQ. For ODOT, which also had the incentive of avoiding facing the conformity requirements that could potentially challenge some of their transportation expansion plans, Ozone Alert! and the projects included in the EAC were low cost and relatively low effort.\textsuperscript{290} Ozone Alerts! are only activated during the ozone season, from late spring to early fall, and even then on an episodic basis, and the messages are standard messages taking advantage of VMS already in place. ODEQ also had the incentive of avoiding non-attainment, and the need to undertake SIP development and possibly begin to regulate mobile, stationary and area sources. Therefore, the major actors in transportation and air quality all had a mutual interest in finding low-cost projects for emissions reductions. The EAC has so far proved to have been unnecessary, as Tulsa would have been designated attainment for 8-hour ozone even without it. Yet, the measures contained in the EAC, in many cases had already been implemented, and those that had not, were already planned by the transportation agencies for their congestion benefits. Therefore, including these measures in the EAC avoided having to include some of the more intensive measures considered earlier, such as inspection and maintenance.\textsuperscript{291}

While smaller cities may not have the internal resources necessary to undertake innovations, their “smallness” can facilitate coordination, both because the number of agencies that need to coordinate is smaller, and the organizations themselves are smaller. In the case of Tulsa, communication between agencies was easier because of the greater ease of one-on-one contact between staff from different agencies. In this case, one could suggest that the transaction costs – first, identifying who to talk to, and second, negotiating the terms of cooperation between agencies – are lower. For this reason, the Ozone Alert! program, in which variable message signs are used to inform drivers of a pending high ozone day and to promote alternative commutes such as carpooling or transit or changes in departure times, could be implemented with relative ease, even though it requires the cooperation of the Oklahoma Department of Environmental Quality, INCOG, Tulsa City/County Health Department, and the Oklahoma Department of Transportation. Indeed, in preparing for the site visits for the cities with larger agencies, identifying the key people within each organization for both ITS deployment and air quality management and planning was substantially more difficult. For Tulsa and Orlando, the key individuals could more readily be identified, and there was more consensus among interviewees who the “important” individuals were for issues of ITS and air quality.

Returning to the issue of cost, in an interview with the Oklahoma Department of Transportation, it was stressed that Tulsa is a “donor state” with respect to national fuel revenues, paying more in gasoline taxes than they receive when those monies are redistributed to the states (ODOT interview, 2005). Therefore, although they would like to do more with ITS in Tulsa, the funding is not available. Furthermore, although they have received some federal grants for ITS work, the focus of those grants has more often been on integration, rather than on deployment. As a result,

\textsuperscript{290} In fact, many had already been implemented when the EAC was submitted.

\textsuperscript{291} These measures were considered as a part of the list of all possible local emissions control measures that was required as a milestone commitment for the EAC. See Chapter 5 for the history and timeline of the EAC development process.
ITS is seen as a system improvement that agencies cannot “afford.” However, Tulsa was still able to innovate.

6.2.5.4 Conclusion

The case of Tulsa, particularly in comparison with that of Orlando, highlights the relative importance of problem severity over other factors such as internal resources, but also factors such as cost. In anticipation of an important problem for all agencies involved, there were mutual benefits in identifying some innovative actions to address their circumstances, i.e. a few days of high ozone levels threatening to push the area out of attainment. These are not the most technologically sophisticated innovations, but does reflect some innovative thinking and high levels of collaboration among agencies in how to address this problem quickly, at a lost cost, and in a manner tailored to the specific air quality situation of Tulsa.
6.3 EVALUATING THE THEORETICAL FRAMEWORK

Thus far, we have developed a set of specific and testable propositions (Chapter 4). At the same time, the cases were investigated and described in depth, in order to capture the additional contextual factors that might have implications for the outcomes (Chapter 5). In this chapter, we tested the predictive power of our theoretical construct for five case study cities. To support this effort at theory building and testing, we developed a semi-quantitative method for comparison of case study outcomes (Chapter 4), introducing a scale for IIDAPT. We first assessed IIDAPT levels for individual technologies, and used three measures to scale-up from IIDAPT for individual technologies to overall IIDAPT outcomes at the metropolitan level (see Appendix E for the full calculations). This enabled us to gauge the overall “innovativeness” of metropolitan areas in using ITS for air quality objectives. Having presented the predicted and actual outcomes on a case-by-case basis, we will now look at the overall performance of the theory for all five cases, addressing the following questions:

- How well did our theory of IIDAPT perform in predicting actual outcomes?
- What conditions were the most important in predicting outcomes?
- What conditions were the most important in explaining outcomes?

The following section (6.4) will then evaluate the policy implications of the results of our analysis. In addition to looking at the predictive and explanatory elements of our theoretical framework, we will extend it to provide prescriptive advice so that metropolitan areas that may be considering innovation and adaptation in their deployment of ITS for air quality, can assess their probability of success (according to the predictive element) and identify actions to improve their odds (according to both the predictive and explanatory elements). In other words, for areas interested in undertaking Integrated Innovation, Deployment and Adaptation of Public Technologies, will they succeed and how can they improve outcomes?

6.3.1 How well did our theory of IIDAPT perform in predicting actual outcomes?

In Table 6-17, we aggregate the cross-case results to assess how well the theory of IIDAPT accurately predicted IIDAPT outcomes, as based on the seven conditions. Looking at the summary measure for actual outcomes, the results are closely in line with the predicted outcomes for all five cities. Houston, with the highest predicted level, was also the highest actual IIDAPT at 5.2. Los Angeles, which we predicted to be medium to high, followed with 4.0. Boston and Tulsa both had actual outcomes of 2.3, which was in line with predicted outcomes for Boston, but slightly high for predicted outcomes for Tulsa. Orlando, as expected, had no IIDAPT. These results indicate that our theory performs well in predicting actual outcomes.
Table 6-17 Predicted versus actual IIDAPT outcomes

<table>
<thead>
<tr>
<th>Predicted outcomes</th>
<th>Houston</th>
<th>Los Angeles</th>
<th>Boston</th>
<th>Orlando</th>
<th>Tulsa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actual outcomes</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.2</td>
<td>4.0</td>
<td>2.3</td>
<td>0</td>
<td>2.3</td>
<td></td>
</tr>
<tr>
<td>* Average level</td>
<td>High</td>
<td>Med-high</td>
<td>Medium</td>
<td>None</td>
<td>Medium</td>
</tr>
<tr>
<td>0-6</td>
<td>4.5</td>
<td>3.8</td>
<td>2.9</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>* Range</td>
<td>4</td>
<td>8</td>
<td>4</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>0-10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>* Intensity</td>
<td>29%</td>
<td>13%</td>
<td>20%</td>
<td>0%</td>
<td>26%</td>
</tr>
<tr>
<td>% of all recent</td>
<td>of all post-</td>
<td>of all post-</td>
<td>of SIP transit commitments</td>
<td>of all EAC</td>
<td></td>
</tr>
<tr>
<td>TCM projects</td>
<td>2000 TCMs</td>
<td>2002 TCMs</td>
<td>commitments</td>
<td>projects</td>
<td></td>
</tr>
</tbody>
</table>

As noted earlier, the quantitative measures are only part of the description of actual IIDAPT outcomes. With these measures, we attempted to codify and more rigorously compare our observations of how ITS was used for purposes of air quality in the five cities. Again, this summary measure for actual outcomes is the product of three measures. First, is the average level of IIDAPT, which represents the average of only those technologies that were included as IIDAPT. Specifically, these technologies had to have at least a minimal level of innovation and cooperation, and have the dual objectives of improving air quality as well as mobility. Therefore, this measure shows that for those technologies considered IIDAPT, how they ranked, on average, according to our (0-6) scale of the “ideal” IIDAPT outcome. Second, we have a measure of range of IIDAPT. This recognizes that while some cities may be highly innovative in a few areas, such as transit ITS or ITS-based traffic flow improvements, they may not be consistently innovative across different modes and application areas. In contrast, some cities may not have been highly innovative for individual applications, but deployed these types of innovations across a larger number of applications. Therefore, this addresses the question of whether there were there missed opportunities in some application areas (e.g. freeway management, transit operational improvements, etc), and to what extent cities have a diverse set of technologies (0-10) in their “portfolio” of IIDAPTs 292 Third, we want to address the question of how intensively ITS is used as a emissions reduction measure for mobile sources. For this measure we use the percentage of ITS projects or ITS-enhanced projects out of all transportation control measures (TCM) contained in the recent air quality plan for the metropolitan area. 293 This gives us a sense of how often ITS is used as a measure to reduce emissions, compared to other non-ITS TCMs for reducing emissions through transit, trip reduction programs, ridesharing, traffic flow improvements, and so on.

292 Instead of looking at both average levels and range, another approach would have been to simply sum all IIDAPT outcomes for the ten application areas (with an upper limit of 60, with all ten technologies). Another approach would have been to average over all ten application areas. Thus, metropolitan areas that did not have an example of IIDAPT for a specific application area, would be counted as zero for failing to innovate in that specific area. However, we felt that keeping these two measures as separate would better highlight the different approaches in each metropolitan areas. For example, LA has a greater range, but somewhat lower innovativeness, while Houston has fewer applications, but each one is high on the scale of IIDAPT.

293 We use the state implementation plans (SIPs) to identify the TCMs included for the non-attainment area. For the case of Tulsa, with does not submit a SIP, we used the Early Action Compact, which included TCM-like projects.
Again, our actual outcomes were closely aligned with predicted outcomes, according to the summary measure in Table 6-17. Yet, we can gain additional insights from the theory and the cases by looking at the variations in these three sub-measures: average level, range, and intensity. Comparing average levels of IIDAPT to the predicted IIDAPT, we again see a close correlation – from Houston with a high level (4.5) to Orlando with none (0). The exception is Tulsa, again ranking somewhat higher than predicted. Therefore, there are no major surprises when using average levels of IIDAPT as a measure for predicted outcomes. Yet, when we turn to the range and intensity of ITS, the results begin to show some interesting variations.

What we find, looking at range and intensity, is that Houston had a surprisingly low range of IIDAPT. We identified IIDAPTs for only four of the ten ITS application areas in Houston. These four IIDAPTs were all related traffic-flow improvements and HOV/ridesharing-support projects. There was a peculiar absence of ITS-based measures for transit improvements. Despite the fact that there have been efforts underway to improve transit and enhance ridership with ITS, these are not linked to official air quality management efforts. One could argue that this is because ridership increases and mode share shifts are not cost effective measure for reducing emissions. Yet, this would not account for the use of light rail as a measure in the Houston region’s air quality plan. On the other hand, the intensity of ITS in the package of TCMs is high, representing nearly a third of all projects. As described earlier in Section 6.2.1.3, for Houston, interests aligned in favor of the intensive use of ITS-based traffic flow improvements for air quality, through congestion mitigation. At the same time, there were no comparable mutual benefits from promoting the air quality benefits of ITS-enhanced transit, according to the

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294 To reiterate, this does not mean that they do not have air quality benefits. However, there is no “credit taken” for emissions reductions in any of the Houston area’s air quality management plans or programs. Neither has funding through CMAQ been sought.
interests of the agencies involved. However, intensity was very high, which is compatible with the mutual interests of the agencies involved, which all preferred technology-based measures over behavior-based measures to improve air quality.

Los Angeles, on the other hand, appears to have taken the “shotgun” approach to experimenting with ITS to support emission reductions strategies. We identified examples of IIDAPT for eight of the ten ITS application areas (the highest “range” of our five cases). While some individual technologies were a “miss” with lower levels of IIDAPT (lower innovation, cooperation, assessment and adaptation), projects like the universal fare system were “hits” with very high IIDAPT levels. Ridematching services (ridematch.info) for the five county area and the City of LA’s adaptive traffic signal control system were also a strong examples of IIDAPT, with average levels between 4.5 and 5.5. LA’s high range could be partially explained by the large number of agencies, which makes us reconsider the impact of this condition, which was not considered to be a strong predictor in our theory, when we reviewed the cases on an individual basis above. Because transportation planning is a highly decentralized process in the LA region, with 88 cities, six counties, and fourteen sub-regional associations, there is a greater number of opportunities for innovation, although each innovation on its own may not necessarily a high-level of IIDAPT. Congruent with the fact that LA must also implement an extremely large number of projects in order to improve air quality, we find that ITS comprises a low share of TCMs, at 13% of post-2002 projects. This low share of ITS in the mix of TCMs, also relates to the relationship between the transportation agencies and air quality agencies, and their less favorable perceptions of possible mutual benefits from using ITS for air quality through traffic flow improvements. It suggests that the air quality agencies are not convinced by the potential air quality benefits of ITS, and therefore are not motivated to incorporate ITS more liberally in its air quality plans. Thus, the larger number of air quality agencies, per se, is not a barrier to coordination on the use of ITS for air quality. Rather, is seems that barriers to coordination emerge not necessarily because of a larger number of agencies, but a failure to find actual mutual benefits in using ITS for air quality.

Boston had a high intensity, compared to a weaker average level and smaller range of IIDAPT. Boston’s intensity was somewhat higher than predicted. Yet, it makes sense when we consider it within the context of the transit agreements, and the agenda of substitution of ITS-enhanced transit services for the earlier transit commitments. As a result, there were stronger mutual benefits in this application area, as described earlier in Section 6.2.3.

Tulsa was slightly higher than predicted on all measures. For Tulsa, the use of attainment status as a measure of the condition of problem severity led us to underestimate Tulsa’s IIDAPT outcomes – as, in judging problem severity, we did not fully take into consideration the seriousness of close calls with non-attainment – first in the early 1990s with 1-hour ozone, with the threat of non-attainment again rearing its head more recently with the new 8-hour ozone standard. To the planners in Tulsa, the possibility of being designated non-attainment was enough of a threat to spur innovation. The high intensity, relative to the other cities was

IIDAPT intensity in Houston was even significantly higher during earlier time periods, with ITS representing up to 87% of all TCM projects and 81% of total project costs for all TCMs (see Table 6-5 and Table 6-6).
somewhat misleading, however, as it is more a result of how individual projects are listed in the Early Action Compact, compared to the other cities for which we could use the official state implementation plans (SIPs) submitted to EPA as a consistent reference. Because there are few and small-scale projects listed in the EAC, individual intersection signalization improvements are counted as a project. In comparison, other cities will list projects in terms of corridors or larger areas.

The question is, do these apparently anomalous outcomes provide us with additional insights into the theoretical framework we have constructed? Does it prove or disprove some of our earlier assertions? What does it mean for the seven conditions we identified? To answer these questions, we will discuss the theory in terms of its ability to predict outcomes, and its ability to explain outcomes.

6.3.2 What conditions were the most important for predicting outcomes?

In order to test the theoretical framework, comparing what the seven conditions would predict with what the actual outcomes proved to be, we had to develop consistent measures for those conditions in order to provide uniformity across the cases (see Table 6-1). Comparing the predicted and actual levels of IIDAPT, we found that overall, the seven conditions, even in their more simplified form, were good predictors of IIDAPT outcomes. In this section, we attempt to identify more specifically which of those seven conditions were the strongest predictors of IIDAPT outcomes. We will begin discussing the most important conditions for predicting IIDAPT outcomes, and then briefly review why some of the other conditions were not as strong as predictors.

The strongest predictor of IIDAPT is problem severity. This is an essential condition. In the absence of a problem, as in Orlando and Tulsa, levels of innovation should be low, if at all. Indeed, Orlando was an informative case in that there was no innovation, despite the other conditions, such as internal resources, in its favor. As problems become more pressing, as for Los Angeles and Houston, we saw more innovation and IIDAPT as those cities struggled to deal both with congestion and air quality. This confirms earlier studies of innovation in the public sector, that problems are a key condition leading to innovation (Borins 1998; Sapat 2004). However, it should be stressed that for our five cases, the perception of problem severity is not necessarily based on the physical problem (i.e. parts per million of ground-level ozone), but rather on the regulatory pressure to address that problem. For this reason, we can also envision a threshold effect, in which areas not meeting standards (non-attainment areas) face strict regulatory requirements and therefore innovate, whereas areas that are not required to meet these same requirements (attainment areas), do not innovate. We will explain later where Tulsa falls in this pattern.

This result is important, and optimistic from the viewpoint of the efficacy of more stringent federal regulations in spurring innovation by local governments. Clearly, Los Angeles has made very important progress in reducing ozone levels. But, even in the absence of an acute crisis, for example, highly visible pollution episodes with very palpable health effects on the general
population,296 the regulatory pressures stemming principally from the Clean Air Act Amendments continually stimulate innovation. This confirms earlier studies,297 that have challenged what was for long the conventional wisdom — articulated most strongly by Wilson — that public sector innovation occurs primarily in response to major crises, and that even under crisis, innovation may not occur. As noted by Borins:

“If public management innovation were solely the result of crises, we would likely conclude that public sector organizations are characterized by uncaring people who do not act until problems become crises, or they are gridlocked systems that do not permit actions until problems become crises. In fact, we have seen that, in the majority of cases, public servants were able to act to resolve problems before they become crises, or to take advanced of opportunities to deliver new services or to deliver existing services more efficiently.” (Borins 1998, p 47).

Our case studies reflected this same issue, that innovation occurred even without having a crisis situation in the public eye. We will discuss problem severity more below.

Earlier we defined mutual benefits as the requirement to meet transportation conformity requirements — for example, implementing transportation control measures and meeting mobile source emissions budgets. This suggested there would be mutual benefits to transportation agencies and air quality agencies from finding synergies between ITS deployment goals and related mobility improvements (both for individual drivers and transit users), and air quality goals. Therefore, as a first cut in identifying mutual benefits, we suggested that agencies define their agency goals in relatively simple terms. Air quality agencies want to improve air quality, presumably in the most efficient manner; transportation agencies want to improve mobility, again, in the most efficient manner. If ITS can be deployed to accomplish both objectives, it creates mutual benefits. Overall, the predictive power of using this condition was fairly good. Agencies did seek out TCMs that took advantage of existing/planned improvements from ITS, as a seemingly “win-win” solution, and used CMAQ funds for ITS technologies that could improve air quality.298 Yet, it is interesting to take note of instances when agencies did not take advantage of ITS projects that, in simple terms, could be considered to provide mutual benefits. We will therefore re-examine this assumption below.

Dedicated resources illustrated another condition that worked well as a predictor of IIDAPT outcomes. As we could see, CMAQ funding in most cases did provide a “slack” resource for experimentation with ITS and other measures for reducing mobile source emissions. Also, as we

296 We use crisis in the sense that Kingdon describes, that an issue has come to the immediate attention of policymakers, the public, and the media. For example, in California, in 1903, residents mistook heavy industrial smoke and fumes to be a solar eclipse. After the first recorded photochemical air pollution episode in 1943, the Bureau of Smoke Control was created (1945). Visibility during that event was three city blocks. The most “devastating” air pollution episode (albeit different pollutants) occurred in London in 1952, when 4,000 people died from the “Killer Fog.” Molina, L. T. and M. J. Molina, Eds. (2002). Air Quality in the Mexico Megacity: An Integrated Assessment. Boston, MA, Kluwer Academic Publishers.


298 Indeed, the CMAQ program itself was created on the assumption of mutual benefits between projects that improve congestion mitigation and air quality.
suggested, dedicated resources can also reinforce the sense of mutual benefits, by providing a monetary incentive for transportation agencies that might not otherwise have an interest in looking at the air quality impacts of their transportation management strategies. Particularly for Houston and Los Angeles, the CMAQ program seemed to enable actions that might not have been undertaken otherwise. As suggested in Figure 6-1, the dedicated resources therefore reinforce or create new sources of mutual benefits.

Therefore, we found that of the seven conditions, problem severity, dedicated resources, and mutual benefits were the most important predictors of IIDAPT outcomes. What we did not find, was that the emergence of new and/or better information regarding the air quality impacts of ITS – whether positive or negative – led to adaptation by agencies, in order to improve air quality outcomes. While there were, at times, comprehensive assessments of the overall performance of ITS applications, the information on air quality outcomes was usually secondary to other mobility-oriented benefits. Therefore, adaptation of ITS technologies would support better mobility outcomes, but not better air quality outcomes.

In our theoretical framework, we suggested (by the dotted line) that the generation of new information in the case of ITS and air quality could actually change the perception of agencies regarding the existence of mutual benefits. However, while this connection between information and mutual benefits did exist, information was not used to adapt technologies. We found that new information on air quality benefits did not change the status quo in favor of greater air quality benefits, rather, it reinforced the status quo. This is reflected in the assessment methodologies for CMAQ projects. Houston had methodologies to evaluate arterial traffic flow improvements from ITS that would show the emissions reductions from reduced congestion, in order to document these benefits for CMAQ funding. However, the methodology did not force the consideration of induced demand. Doing so may have undermined their ability to access CMAQ funding. On the other hand, Los Angeles, developed a methodology similar to that of the Houston methodology to measure emissions reductions from traffic flow improvements, but then lowered the estimated emission reductions by half to incorporate the concerns of air quality agencies regarding induced demand. In this manner, air quality agencies in LA raised the bar for proving the air quality benefits of ITS-based traffic flow improvements. Again, this would reinforce the existing perception that there are not necessarily synergies between traffic flow improvements and air quality improvements, rather than change perceptions of mutual benefits.

Internal resources were not a strong predictor of IIDAPT outcomes. Although the larger and better equipped agencies in bigger metropolitan areas were more innovative, size and resources did not seem to be a critical barrier to innovating. Neither did they enable innovation where there was no significant problem. We saw cases of smaller agencies in larger cities innovating, as well as smaller agencies in smaller cities innovating. For example, in the case of Los Angeles, the City of Los Angeles had a very high level of internal resources, with an innovative staff extremely proficient in the arterial traffic management systems (see Table B-14). However, even smaller cities and smaller transit agencies in the Los Angeles metropolitan area were also able to deploy technologies in support of air quality benefits, largely enabled by the dedicated resources created by the CMAQ program (see Table B-19). Clearly, agency size can determine the scale of the innovation, and perhaps the “innovativeness” in terms of technological novelty of the system.
However, looking at the case of Tulsa, where we did not expect innovation, we found that even with lower internal resources, both for ITS and for making the links between ITS and air quality (for example, analysis of air quality benefits had to be contracted out), they were able to use already deployed technologies to innovate through the Ozone Alert! program. This program even caught the attention of the EPA as a case study for air quality management (see Table B-38). While Tulsa probably would not have been able to develop adaptive traffic signal control systems as the City of Los Angeles, or create a TranStar type facility, they can and have innovated in ways appropriate to their particular problems and challenges.

We also proposed earlier that the lower cost of most ITS technologies, compared to conventional infrastructure improvements, can boost the attractiveness of improving transportation services and air quality using ITS. "Measuring" the relative influence of this condition was difficult, as it would require comparisons between deployed ITS projects, and the hypothetical conventional projects it may have replaced – if it actually replaced conventional infrastructure at all. The availability of ITS as a lower cost transportation improvement did have an influence on IIDAPT outcomes. However, the direction of this influence could not be predicted without understanding the underlying agency interests (and therefore mutual benefits). The case showed that the perception of ITS as a lower cost alternative could either work against or in favor of using ITS as a measure for air quality improvements. In order to understand how ITS, as a lower cost option, affected IIDAPT outcomes, we have to look at how it may have affected the perceptions of mutual benefits, according to the interests of the individual agencies. Therefore, the predictive power of this condition is weak. But, it can support the explanatory power of the theory, as explained below.

Finally, we look at the number of agencies. The influence of this condition is uncertain. We had originally suggested that this condition would be the Achilles’ Heel of Los Angeles. With such a large number of transportation and air quality agencies involved, we believed that coordination failures in approval and implementation would lead to a lower level of IIDAPT that might otherwise be possible. On the other hand, in Houston, a smaller number of agencies and more centralized ITS operations and management through TranStar, following the same logic, would increase the probabilities of successful IIDAPT. However, while we focused on the influence of the number of agencies on cooperation, we overlooked an important dynamic, which is the influence of the number of agencies on the frequency and range of innovation. In the case of Los Angeles, the more decentralized transportation decisionmaking process seems to have enabled a greater range of IIDAPT, with many smaller agencies deploying different ITS technologies in support of air quality as well as mobility. Therefore, we may be seeing more true experimentation in the case of LA. Houston, on the other hand, with a more limited number of agencies, and more centralization transportation decisionmaking and highly coordinated ITS efforts through TranStar, may have limited the range of IIDAPT to only four application areas. Therefore, while the case studies did not provide conclusive results for the impact of a larger number of agencies, they did point to some interesting avenues for future research.

6.3.3 What conditions were the most important for explaining outcomes?

The previous section highlighted three conditions – problem severity, mutual benefits, and dedicated resources – as the strongest predictors of IIDAPT outcomes, in terms of the actual outcomes as shown in Table 6-17. However, looking more closely at the measures of IIDAPT used – average level, range, and intensity – we identified some apparent deviations from what our conditions may have predicted. As discussed in Section 6.3.1, we can gain additional insights from the theory and the cases by looking at the variations in these three indicators. These "inconsistencies" point us to where we can probe deeper into the explanatory power of the theory, and perhaps refine our understanding of the conditions. Therefore, this section will expand upon the discussion in Section 6.3.1, where we discussed reasons for the variations from the predicted outcomes for range and intensity of IIDAPT.

While the seven conditions did point us in the right direction for predicting IIDAPT outcomes, many important factors emerged from the broader transportation and air quality planning context: e.g. the Big Dig and SIP transit commitments in Boston, and the shift toward major transit investments and TDM strategies in Los Angeles, an agenda of highway expansion and light rail for transit in Houston. These are factors that are important to incorporate in a case study format, but that cannot be fully captured when defining a limited set of conditions. Therefore, outcomes have to be understood within the local context. In particular, we find that promoting the air quality benefits of ITS can either support or detract from preferred categories of investments. However, how this plays out differs greatly from one area to another. In Boston, the strategy was to highlight the possible improvements from ITS for transit improvements, as potential replacements to other, more capital intensive, transit commitments, while in Houston, the same strategy might have undermined their agenda of implementing new light rail services. Therefore, the local context, by influencing mutual benefits, can determine which application areas will have more IIDAPT, and which areas will not. As a result, it will also determine the range of IIDAPT, if efforts are more concentrated in certain types of ITS applications (i.e. transit, traffic, demand management, etc).

6.3.3.1 Problem Severity

Problem severity, using the 1-hour ozone designation, was a good predictor of IIDAPT, as described earlier. However, it is important to note that the physical air quality problem can fluctuate, while the regulatory designation is relatively more constant. We have seen Los Angeles (extreme non-attainment) and Houston (severe non-attainment) – the two highest IIDAPT innovators – alternate in terms of which city actually had the worst air quality for a given year (measured, for example, as the number of days in exceedance of ozone standards). Potential changes to this regulatory designation, were also part of the problem definition. Tulsa, like Orlando, was in attainment, but innovated with ITS for air quality purposes substantially more. This occurred despite its other comparative disadvantages to Orlando in terms of a low base of ITS and low internal resources. Tulsa nearly went out of attainment and thus took actions to avoid non-attainment status. We will focus on this issue of problem severity, because in our cases it was the most important predictor, and often appears in the literature on innovation in government as the key stimulus to innovation.
We compare our definition of problem severity with that of Borins (1998), who identified “internal problems” as “the most frequently occurring set of conditions leading to innovation based on his sample of winners of the Ford Foundation-Kennedy School of Government awards for innovation in government. He groups agencies’ internal problems into the following categories: (1) failure to reach market or target population, (2) being unable to meet the demand for services, (3) increasing financial or other resource constraints, (4) falling behind changes in the environment, and (5) failure to coordinate policies (Borins 1998, p 42). He then looks at another category of conditions leading to innovation, which is crisis or failure, setting crises “apart from internal problems by adding the element of external visibility,” meaning that the internal problem now has the attention of the general public (ibid, p 44). Third, he adds another condition, “political factors,” noting that the most frequent political factor is legislation (ibid, p 45). We review these definitions because they can provide insights as to how to more accurately describe problem severity in the context of our cases of IIDAPT.

This dichotomy between internal problems and crisis/failure, and considering legislation as a entirely separate condition for innovation, misses some important factors. First, there does not necessarily have to be a crises or failure for a problem to have external visibility. Except for rare episodes such as the London “Killer Fog,” air quality problems are not usually considered to be crises. Yet, they are problems that are “manifestly visible” to the public, such as in Houston and Los Angeles. Second, the issue of when something has “external visibility” has to be examined more closely. The “public” is not a comprised of homogenous and diffuse stakeholders. More typically, there will be more concentrated groups of stakeholders, to whom the issue is highly visible. In some cases, these stakeholder can force an agency’s internal problems to the public agenda. In Boston, the transit agreements and their role as transportation control measures, are the focus of influential stakeholder groups and citizens, primarily the Conservation Law Foundation. If these groups did not keep the pressure on the MBTA and EOT to fulfill these commitments, they would likely lose their importance for those agencies. Finally, as Borins notes, agencies also innovate in response to anticipated crises, indicating that agencies are more forward looking than many studies of organizational theory recognize. Agencies in Tulsa thought they were going to fall out of attainment with the 8-hour standard; earlier, they also thought the same with the 1-hour standard. This situation, for Tulsa, was highly problematic. We could also propose that, as the other side of the coin, if a problem is anticipated to be resolved due to factors beyond the control of the agencies, there may be lower levels of innovation. For example, air quality in Boston is probably going to improve independently of any transportation control measures (perhaps even including the transit commitments) because of reductions in NOx from states upwind. Therefore, there is a less intense focus on identifying measures to reduce emissions and implement additional TCMs beyond those still required by the transit agreements.

301 This is the result of the OTAG work and “NOx SIP call” described in Chapter 5. Upwind states had to develop plans to reduce their contribution of NOx to downwind states, mainly through controls on industrial emissions.
Also, if we consider the role of legislation, we can see that problem severity is closely linked to legislative changes. Legislation at the state or federal level can radically change the definition of the problem definition for agencies. Increasing regulatory stringency moves the "target" for acceptable agency performance, and targets/objectives that public agencies have to reach (such as air quality standards). Therefore, summarizing the above discussion, we could break down our condition of problem severity into the following categories:

- the extent of the physical problem,
- pressure for change or action by stakeholders,
- pressure for change or action by the general public,
- difficulties in meeting federal requirements or standards, and
- anticipation of important changes in any of the above.

We go through this exercise because it will be important for the later discussion on the policy implications of our results (Section 6.4). However, we emphasize this issue as an important theoretical contribution, because it highlights how local innovations are embedded in the federal system in the US. Definition of a "problem" for local agencies, is highly influenced by national guidelines or regulations. This fills in a conceptual gap, in that we explicitly link state and local innovation to federal regulatory actions. 302

6.3.3.2 Mutual Benefits and Cost

Mutual benefits, an important condition, depends on the local context for its full explanatory power (see Figure 6-1). As a result, it cannot be fully determined beforehand as a predictive condition. Defining mutual benefits, in its more simple form, does point us in the right direction for IIDAPT outcomes, but may mask some of the underlying dynamics. For this reason, we see some divergence in range and intensity of IIDAPT as described earlier. Therefore, we would consider it more as part of our theoretical framework's explanatory power, rather than as a predictor. As described earlier, mutual benefits are based on agency interests, not just on agency missions/policy objectives. Because innovations with ITS for air quality do not take place in a vacuum, they will be competing with other projects both for mobility and for air quality. An agency's interest or preference to deploy ITS with the additional objective of air quality improvements depends on whether it fits, or not, with the agency's interests. Because it might be seen as competing with other projects that might be higher priority for the agencies, our condition of cost also comes into play. If ITS is promoted as a low-cost measure to achieve various objectives, it may undermine the ability of agencies to make a case for their preferred investments, which might be more capital intensive. Therefore, our cases illustrated that we had to analyze the self-interests of agencies in order to determine their mutual interests, and ask what are the repercussions – positive and negative – of highlighting ITS as a low-cost improvement for both mobility and air quality.

302 For example, in Houston, interviewees referred to the lack of federal guidance on air toxics, in a manner similar to the criteria pollutants with specific standards, as making it difficult to respond to this problem. Thus, little has been done for reducing air toxics at the local level.
6.3.3.3 Dedicated Resources

The explanatory power of dedicated resources closely follows the logic behind their predictive power. Outcomes can be determined in part by looking at an agency’s strategies for accessing CMAQ funding. Houston saw an important funding source for their ITS initiatives. Los Angeles did as well. Boston was an interesting case in this respect. As seen in Table 6-11, ITS was not a significant percentage of projects with CMAQ funding. In the latest transportation improvement program, only 2% of CMAQ dollars went toward ITS projects (representing 8% of all projects). Boston therefore illustrates the case when dedicated resources do not have the “slack” that they were intended to have. CMAQ resources were used less for experimentation with measures to reduce emissions, and more to deal with a backlog of more traditional projects that had difficulties securing funding because of the pressures created by the Big Dig.

6.3.3.4 New Information

We also saw that the presence of dedicated resources, through CMAQ, seemed to have influenced the “new information” that was generated, in the form of ex ante studies to justify the inclusion of projects in the CMAQ funding category. Perhaps for this reason, we saw little adaptation to new information. The information was more frequently generated to support access to dedicated resources. As a result, rather than new information influencing the perception of mutual benefits, as proposed earlier, new information tended to reinforce mutual benefits. Because air quality was often the “secondary” policy objective, new information tended to support core agency interests. Where air quality could be shown to be an additional benefit to the mobility benefits, that information was highlighted, and used to include the measure as a TCM, or fund it with CMAQ. On the other hand, where information, usually externally generated, showed emissions increases, that information was ignored. The author found no examples of the use of information showing negative emission impacts to adapt or change the design or operation of the technology, or even influence future technology deployment, in ways that would reduce the negative impact.

6.3.3.5 Internal Resources

We found that internal resources were not a good predictor or IIDAPT at the metropolitan level. However, looking at the technologies for IIDAPT, and the agencies that were deploying them, we found that larger agencies were often responsible for the more innovative IIDAPT outcomes. Furthermore, for IIDAPTs with high levels of cooperation, it was often the larger agencies that took the lead on technology deployment. For example, Metro was the lead agency for the Universal Fare System for LA County using smart cards. They were able to bring all of the smaller agencies on board to the systems, having been the first to procure it from Cubic.

Therefore, while not a good predictor of IIDAPT outcomes at the metropolitan level, it can provide insights regarding which agencies in a metropolitan area are more likely to innovate.

Finally, as discussed earlier, we could not identify a significant impact from the condition of number of organizations. The most extreme case in this respect was Los Angeles. As discussed above, while this could be detrimental to cooperation, it may have also created a more prolific ground for innovation. One theory could be that through competition among a number of cities and counties - competing for CMAQ funding for example - a broader range and diversity of innovations will emerge. More centralized allocation of these resources, such as in Houston, may narrow the range of innovative outcomes by concentrating them in certain, higher priority areas, such as supporting TranStar deployments.

We have found that the seven conditions identified and described in our theoretical framework can predict IIDAPT outcomes for a metropolitan area with good agreement between predicted and overall actual outcomes. Furthermore, where some of the sub-measures of actual outcomes differ from predicted levels, we found that the theoretical framework can be used to explain the reasons for some of those apparent discrepancies, enabling us to further refine this framework. We will now look at the application of this framework to develop policy recommendations based upon what we have learned about the conditions leading to IIDAPT.
6.4 IMPLICATIONS FOR POLICY

What are the policy implications of what we have learned from these cases and our theoretical construct? We suggest there are three important contributions to policy. First, having identified the conditions that are necessary for IIDAPT, we can develop a “checklist” for other cities that may want to assess their “readiness” for IIDAPT, and identify changes that could be made to improve the probabilities of IIDAPT. Second, we will draw some generalizations, based on this cross-case analysis, on whether US cities have been doing a good job, or not, integrating air quality concerns into ITS deployments. Finally, we will look specifically at whether the transportation conformity framework and CMAQ program, are pushing cities to better integrate air quality objectives with ITS deployment, and what changes could be made to promote greater levels of IIDAPT.

6.4.1 Four Areas for Policy Intervention

In addition to their predictive and explanatory role, we suggest that these conditions also have a prescriptive role. Because we found that the IIDAPT framework – in particular, the conditions of problem severity, mutual benefits and dedicated resources – could used to predict outcomes, they can also be used to assess the possibilities for IIDAPT. Furthermore, we can use this information to identify policy interventions that could increase the likelihood of successful IIDAPT, for areas with lower levels of predicted IIDAPT. This clearly has a normative component. It follows from the assumption that fostering technological innovations (such as with ITS) that achieve multiple policy benefits (such as air quality improvements, congestion mitigation and improved transit) is desirable. However, one may argue that this is not the best or socially “optimal” strategy, and that other types of changes – for example, social change that fundamentally alters travel behavior and choices – are required instead.

With that caveat in mind, we will propose four policy interventions for improving IIDAPT outcomes. We emphasize that these policy interventions are based on a limited set of case study cities in the US, although we will assess their applicability to an additional case outside of the US in the following chapter. Moreover, these policy inventions are developed for the case of ITS and air quality. Therefore, we caution readers against considering these policy interventions more broadly for non-US contexts, and for technologies and issue areas not related to ITS and air quality. In the concluding chapter, however, we will look at future research possibilities, including the extension of the IIDAPT framework to other technology and policy domain areas.

In the previous sections, we focused on three important conditions as predictors of IIDAPT – (1) problem severity, (2) mutual benefits, and (3) dedicated resources. We will discuss these as possible areas for policy intervention to improve the likelihood of IIDAPT. We also identify policy interventions related to the condition of new information in the expectation (and hope) that by restructuring the manner in which information is generated and used, more innovation and adaptation can take place in order to maximize air quality benefits of ITS.

- **Policy Intervention 1:** Increase the regulatory stringency for addressing air quality problems in metropolitan areas, to promote experimentation with ITS for supporting air quality goals.
IIDAPT will be likely to occur where the responsible agencies are unable, or face substantial
difficulties, to reduce a problem to an "acceptable" level. Again, problem severity here is
determined by:

- the extent of the physical problem,
- pressure for change or action by stakeholders,
- pressure for change or action by the general public,
- difficulties in meeting federal requirements or standards, and
- anticipation of important changes in any of the above.

Even if a problem itself is not at a crisis stage, regulatory pressure can provide the impetus to
innovate. The severity of the problem will be defined according to the ability of the agencies to
meet those regulatory requirements. Moreover, agencies will respond to current and anticipated
problems. Therefore, more stringent legislation that clearly delineates the extent of the problem
and the progress that needs to be made to bring conditions to an "acceptable" level, can lead to
innovation. Pressure from the general public did not seem to be as important as a motivator to
innovation, although we did not specifically examine this as a separate condition in the cases.
Stakeholders were able to pressure for change (for example, the CLF in Boston), but only where
there were legislative and regulatory requirements that they could use as a basis to threaten
litigation of projects or programs. Therefore, in the absence of a crisis-level problem, it seems
that the most effective strategy for spurring innovation is in the tightening of regulatory
requirements. While innovation was a very local phenomenon, the stimulus for innovation
tended to come from higher levels of government.

- *Policy Intervention 2: Provide dedicated resources that create “slack” for innovation, in
  order to increase the likelihood of experimentation with ITS for air quality purposes.*

Dedicated resources, such as CMAQ, can also be a source of support for innovations that cannot
be funded easily from traditional funding sources. However, to truly be “slack,” they must be
adequately protected from general budgetary pressures for other high priority investments. In
Boston, for example, these funds were not treated as slack resources, and were used for projects
which raised concerns about whether they were indeed the most appropriate projects for this
funding category, given the eligibility restrictions on expansion of facilities for single occupancy
vehicles. For this reason, conditions upon their use and requirements for proving eligibility
(documenting air quality benefits), are imperative.

The amount of dedicated resources should also be proportional to the severity of the problem.
This was done in the case of CMAQ apportionments, which used a funding formula based on
non-attainment status and population to calculate annual CMAQ funding levels for each
metropolitan area. Therefore, areas with the greatest need to innovate (based on non-attainment
status), are given additional CMAQ resources to innovate. The potentially negative aspect is that
“progressive” areas wishing to innovate even in the absence a severe problem, but without the
resources to do so, could not access these funds. However, we saw that in the case of Orlando –
which had a large ITS-base and probably would have had sufficient internal resources to
innovate with ITS for air quality purposes – did not use ITS for air quality in the absence of an
air quality problem. Yet, our case sample was small, and there may indeed be “progressive”
metropolitan areas wanting to use ITS for air quality, but lacking the resources effectively undertake those projects.

We also saw from our cases that dedicated resources are not entirely necessary if a problem has a "crisis" element to it. For example, as in the case of Tulsa, which did not have slack resources, a sense of pending crisis enabled agencies to innovate even in the absence of these resources, and despite more general transportation funding pressures. However, those innovations may not always endure past the crisis stage. As a more stable source of funding, dedicated resources can provide for more continuous innovation and experimentation with new technologies and services rather than one-shot innovations, and can also support innovations that require some start-up time for operations. 304

- **Policy Intervention 3: Identify areas of mutual benefits – and areas of potential conflicts – with regards to the interests and agendas of key agencies, in order to foster cooperation on ITS innovations for air quality.**

On the surface, *mutual benefits* between policy objectives of different agencies should be sufficient to garner support from multiple agencies. But, this does not provide a guarantee that agencies will be motivated to cooperate. We have reexamined the concept of “win-win” outcomes in the public sector, arguing that a simplistic view of organizational preferences can lead to frustration with failures in implementing solutions that should, in principle, support the policy objectives of multiple public sector organizations, and at a low cost. Therefore, from the policy standpoint, what is needed in this case is a policy entrepreneur, who can look beyond whether the technologies simply fulfill the stated missions and policy objectives of the various agencies. While difficult to change the underlying interests of agencies, understanding these interests can help a policy entrepreneur develop a strategy for deploying ITS in ways that create real mutual benefits. By looking at various alternative technologies for mobility and air quality, a policy entrepreneur can determine whether it will undermine the ability of agencies to make the case for their other preferred investments. Another option is to attempt to change how agencies view the benefits of using ITS for air quality purposes.

In some of our cases, particularly Houston, this role of policy entrepreneur was played best by leaders in the MPOs, who were supportive of and enthusiastic about ITS initiatives, and were able integrate those initiatives into air quality plans (as TCMs) and support the necessary analysis to access CMAQ funding. Also, because the MPO works most closely with the state air quality agencies in development of the air quality plans, they are in the best position to assure at least tacit support for ITS emission reduction measures. In Los Angeles, this role has been played in part by the formation of The Partnership, a non-profit corporation created by SCAG (the LA region’s MPO) and SCAQMD (air quality district). The Southern California Economic Partnership (or “the Partnership”) works “behind the scenes” of formal transportation and air

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304 There is, however, a debate by practitioners who use CMAQ funding, regarding the three-year time limit for funding of operations. While some argue that this time should be extended, others suggest that it sets up problems in that programs that are unviable in the long-run are funded, then simply disappear when the funding period expires.
quality management, supporting the use of advanced technologies such as ITS to improve air quality and transportation system management.  

- **Policy Intervention 4**: Restructure assessments and dedicated resources into a more iterative process of experimentation and evaluation, in order to increase adaptation of ITS technologies to improve air quality outcomes.

Unfortunately, our analysis of the five US cases led to some pessimistic conclusions regarding the role of new information in improving the air quality outcomes of ITS. New information, in general, did not appear to promote further adaptation of technologies. Instead, information was used rather selectively by the agencies to support deployments already planned or underway, and reinforce the existing perception of mutual benefits. As a result, there was little effort to reduce many of the major uncertainties regarding the air quality impacts of ITS. While there are mechanisms to support ITS technologies that have positive impacts, primarily through CMAQ funding, there are no mechanisms to modify ITS technologies that have negative impacts. For example, there is no form of Environmental Impact Assessment or other evaluation mechanism for the impacts of ITS. In fact, ITS projects, under the newest transportation bill, SAFETEA-LU (The Safe, Accountable, Flexible, and Efficient Transportation Equity Act: A Legacy for Users), are categorically excluded from the environmental review process under the National Environmental Policy Act (NEPA).

Furthermore, mutual benefits, dedicated resources and new information have become aligned through the use (and sometime abuse) of CMAQ funds. CMAQ funds, a dedicated resource for experimentation with new technologies and other measures for congestion mitigation and air quality improvements, have created a source of mutual benefits for agencies wishing to access that funding. Projects slated for CMAQ funding must demonstrate predicted emissions reductions in order to be eligible for that funding. As a result, agencies have strong pressures for demonstrating the emission reductions from those projects, or they may potentially lose access to those funds.

The generation of new information could be better structured to provide for learning and adaptation. One approach would be to require a more rigorous *ex post* analysis of emissions benefits, focusing on measurable outcomes. A portion of the dedicated funding could be set aside for analysis of emission and air quality outcomes, and verification of *ex ante* and *ex post* analysis of emissions benefits. This information could then be used to provide additional guidance on acceptable evaluation protocols for demonstrating eligibility for funding. Verification of actual emissions benefits, and comparison with emissions benefits estimated in order to show funding eligibility, could be done on an audit-type basis, particularly for those technologies used most frequently, or those technologies with uncertain benefits.

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305 The Partnership was formed by SCAG and SCAQMD “to help in their joint objectives of developing and fostering new technologies that make significant contributions to the achievement of traffic congestion and mobile source emission reduction goals.” For additional background information on the formation of The Partnership, see [www.the-partnership.org/about_us.htm](http://www.the-partnership.org/about_us.htm). Last accessed May 23, 2006.
Another option, relying more on changes in interagency relationships, would be to involve the air quality agencies more intensively in the assessment process. The air quality agencies have taken a relatively “hands off” approach to CMAQ projects, since the funding allocations are the responsibility of transportation agencies. There are different possible outcomes from this strategy. On the one hand, this may lead lower rates of innovation, as the dedicated resources become harder to access because of these stricter requirements. On the other hand, we could also see the quality and novelty of new innovations increase, as less innovative measures are discarded because they cannot clearly meet the emission reduction requirements.

Earlier in this chapter, we discussed the problem of discerning actors’ intentions from their actions. While many of the projects using ITS for air quality represent “good faith” efforts to achieve real emission reductions, other may reflect playing with the numbers to “show” air quality benefits. The cynical interpretation is that many agencies are simply playing the “numbers game” for conformity, manipulating the numbers to show emission reductions from ITS projects used as TCMs or funded through CMAQ. We stress the restructuring of the use of information through *ex post* assessment, as a way to learn from technology deployments, and audit the quality of the projects undertaken in terms of their air quality impacts.

6.4.2 How are metropolitan areas deploying ITS for air quality improvements in the US?

There is an important gap in the literature on the air quality benefits of ITS. On the one hand, there is the more “holistic” approach to assessing the use of ITS in cities. These studies points to how ITS can and should be used to support not only air quality goals, and even more far-reaching goals of promoting sustainable communities. Yet, little information regarding how ITS is actually used in support of air quality and/or other environmental goals is provided. On the other hand, there are detailed studies looking at specific technologies and modeling the air quality impact (see Chapter 2). Yet, studies in this latter category rarely differentiate between deployments that were actually intended to improve air quality, and those that may have had affected air quality positively or negatively, as somewhat a matter of chance. It takes the technologies as given, and does not attempt to link those technologies, and how and why they were deployed, with their actual impact. As a result, it removes the technological artifacts (ITS) from the social, political and organizational factors that shaped the technological development of those systems.306 As a result, it ignores the element of whether ITS can be deployed in ways that improve air quality, *if that is indeed one of the goals*.

Therefore, what is missing is a more broad-based assessment of how cities are actually using or trying to use ITS for purported air quality purposes, and why. This current research begins to answer that question by using a diverse sample of cities, and looking at all ITS technologies with purported air quality improvements, rather than just selecting examples of “good” outcomes. It also points to how to set up this analysis at a national level, in terms of where to look for data on ITS innovations for air quality (i.e. TCM and CMAQ projects) as well as what types of technologies are used, and how to categorize them.

306 Again, the social shaping of technological systems is discussed in the introductory chapter.
6.4.2.1 Overall Assessment

Setting up an ideal “outcome” proved to be a useful exercise, in that it has enabled us to assess progress by the public sector in managing the deployment of ITS technologies and the environmental impacts of those deployments. The results of our analysis leave room both for optimism and pessimism.

- The “good news”

There are reasons for optimism. In our five cases, we saw that federal regulations can be an effective stimulant of innovation at the local level. Problems do not necessarily have to reach crisis levels before public sector agencies will respond with innovative strategies, and seek mutual benefits from new technological opportunities such as ITS. Although we may like to see more true learning through the better use of assessment, we are seeing at least some experimentation with ITS for air quality benefits. As discussed earlier (see the first part of Section 6.2), we cannot always speak to the true intentions and motivations of individual agencies. But, at least there is a growing awareness of the potential for improving air quality through ITS.

The other part of the good news is that there are multiple conditions that lead to innovation. The first condition is the regulatory pressure applied to metropolitan areas that are non-attainment areas. The second condition, is the anticipation or threat of being subject to that regulatory pressure, by being in danger of exceeding the national air quality standards. The third condition leading to innovation is the availability of slack resources to fund experimentation with less traditional approaches to emissions reductions. We can also add a fourth condition for innovation, which is simply running out of options (Los Angeles) by having already “picked the low hanging fruit,” or running out of what are considered to be politically desirable options (Houston).

- The “bad news”

Yet, compared to our “ideal” outcome, there is still a long way to go. We have seen some innovation by agencies with ITS for mobility and air quality, but it is by no means widespread. ITS project managers often view air quality benefits as a “nice” added benefit, particularly if they can access CMAQ funding, but they do not actively seek out air quality benefit. Air quality agencies see some benefits (with some skepticism of emissions reductions from traffic flow improvements), but do not see ITS measures as competing with introduction of cleaner fuels and vehicles. Perhaps most importantly, there will be barriers to the use of ITS for air quality, if the various agencies’ (transportation, air quality, MPO) interests do not align. Yet, there is also the danger that interests align in favor of using ITS for short-term emissions improvements (traffic flow improvements) by improving grams/mile, while lagging behind on the deployment of ITS technologies that represent longer-term solutions to air quality problems (transit ITS, rideshare support, non-motorized travel) by reducing growth in vehicle miles traveled. Mutual benefits, based not just on agencies’ policy objectives, but on their underlying interests, will be based upon broader trends in transportation and air quality, and will be sensitive to the compatibility of
ITS with preferred investment patterns. Transportation agencies are taking advantage of the air quality benefits of ITS, where it serves their interests, but it is not making them “greener”.

We are also more somewhat pessimistic regarding the role and influence of assessment, as earlier discussions describe. Because much of the assessment is aimed at accessing dedicated resources, this has led to some abuse of the system by deploying technologies, based on purported air quality benefits, that are often unproven in their magnitude, and perhaps in some cases, in their ability to reduce emissions. Above all, the question of induced demand from travel time and reliability improvements from ITS, which is not satisfactorily resolved in research (as discussed in Chapters 2 and 3), is generally underplayed or ignored in practice. Only Los Angeles seems to take induced demand from ITS seriously.

6.4.2.2 Mix of ITS used for air quality

We have provided a very broad-based assessment of how our five cities have performed in IIDAPT for ITS and air quality. A more specific question, drawn from the case study work, is what technologies are most commonly used for achieving emissions reductions from air quality. We looked at technologies for ten ITS application areas, their frequency of use for the five case study cities, and average IIDAPT levels. These are listed in Table 6-18.

Table 6-18 Frequency of use and average IIDAPT levels of each ITS application area

<table>
<thead>
<tr>
<th>ITS application areas</th>
<th>Frequency of use (0-5)</th>
<th>Average IIDAPT level (0-6)</th>
<th>Houston</th>
<th>Los Angeles</th>
<th>Boston</th>
<th>Orlando</th>
<th>Tulsa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arterial traffic flow improvements</td>
<td>4</td>
<td>3.9</td>
<td>4.5</td>
<td>5.5</td>
<td>2.5</td>
<td>-</td>
<td>2.5</td>
</tr>
<tr>
<td>Freeway management strategies</td>
<td>3</td>
<td>3.2</td>
<td>4</td>
<td>2.5</td>
<td>3</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Freeway traveler information</td>
<td>0</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Transit information</td>
<td>1</td>
<td>3</td>
<td>-</td>
<td>3</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Multi-modal information</td>
<td>1</td>
<td>4</td>
<td>-</td>
<td>4</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Transit operational improvements</td>
<td>2</td>
<td>3.3</td>
<td>-</td>
<td>2.5</td>
<td>4</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Transit fare payment systems</td>
<td>1</td>
<td>4.5</td>
<td>-</td>
<td>4.5</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Rideshare support</td>
<td>4</td>
<td>3.4</td>
<td>4</td>
<td>4.5</td>
<td>2</td>
<td>-</td>
<td>2</td>
</tr>
<tr>
<td>Demand management/pricing</td>
<td>2</td>
<td>4.8</td>
<td>5.5</td>
<td>4</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Other applications</td>
<td>1</td>
<td>4.5</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>4.5</td>
</tr>
</tbody>
</table>

Looking at the frequency of the use, we find that with the exception of Orlando, all cities have used some form of arterial traffic flow improvements for emissions reductions, and web-based rideshare matching services. The levels of innovation and cooperation varied substantially for the arterial traffic flow improvements. Los Angeles was the most innovative, with its adaptive traffic signal control system, developed in-house, which also allows for transit signal priority. Houston has innovated with the interconnection of signalized intersections back to the TranStar...
facility and incorporation of signal priority, which also requires coordination between Metro, the 
City of Houston, and Harris County. Levels of innovation in Boston and Tulsa were more 
limited. Boston expanded operational hours of its traffic management center with CMAQ 
funding, while Tulsa targeted signal timing improvements for inclusion in its EAC.

The use of ITS to facilitate ridesharing was also popular with all cities, with only Orlando not 
having an online ridematching service. Even in Tulsa, where one might not expect ridesharing 
because there are no HOV facilities to provide travel time benefits to carpoolers or vanpoolers, 
there are ridematch services available online – if not as fully automated as those of Houston and 
Los Angeles. These databases deal with substantial numbers of commuters, with Los Angeles 
having over 250,000 registered commuters in the Ridematch.info database.

Interestingly, although all cities did have some freeway traveler information services, which 
could reduce emissions by routing traffic around congestion, particularly non-recurrent 
congestion caused by incidents or events, none of them explicitly incorporated those services as 
a emission reduction measure. Transit information and multimodal information services were 
used only in the case of Los Angeles, where both applications were used. CommuteSmart.info in 
Los Angeles not only covers five counties, but includes a common user interface for freeway 
traffic information, transit information and planning, carpool/vanpool matching and bicycle trip 
planning. These are innovative and low-cost measures, providing “one-stop shopping” for 
transportation alternatives. However, as with other ridesharing services, there does not appear to 
be detailed evaluation. This might be because the cost of evaluation could potentially exceed the 
cost of the project itself.

Transit, as a whole, is not as well represented in this sample of cities using ITS technologies for 
air quality. Transit operational improvements appeared in two cities, Los Angeles and Boston. 
Los Angeles also used transit fare payment systems (funded through CMAQ) and transit 
information (included as TCMs) as measures for emission reductions. This contrasts sharply 
with the more widespread use of traffic flow improvements, particularly arterial management, as 
a measure to reduce emissions. In part, this may reflect issues with modeling and documenting 
emissions changes. Transit emissions reductions from improved vehicle operations and changes 
in ridership are more certain to reduce emissions, although the magnitude of those reductions 
may vary widely. Therefore, the direction of changes in emissions is certain, while the 
magnitude less so. On the other hand, with the case of traffic flow improvements, the possibility 
of induced demand from travel time improvements and diversion of trips of other routes, or even 
from public transit, as well as the possibility of increasing speeds to ranges where emissions 
factors rise again, suggest that the direction of changes in emissions is less certain. However, in 
the short run, and assuming traffic volumes to be constant, these emission reductions are at least 
much easier to document, even if the underlying assumptions are not valid.

An interesting area for future research would be to develop a larger sample of IIDAPT projects 
from a number of cities using ITS for emission reductions – perhaps based upon CMAQ-funded 
projects or TCMs. We could then analyze the relative frequency of use of different ITS 
technologies, also using a more detailed breakdown of categories of ITS technologies than that
presented in Table 6-18. This could also lead to the development of a database of best practices, for comparing emission reductions outcomes for the same technologies in different contexts.

6.4.2.3 The “Best of” in ITS for air quality

Finally, to ground the above discussion in specific projects and outcomes, we will briefly summarize the “best” examples of the use of ITS for emissions reductions according to our sample. We look at seven deployments, highlighted in Table 6-19. These include all technologies with an IIDAPT level equal or greater than 4.5 (six in total), plus one example of multimodal information, in order to capture at least one example of the use of traveler information as a tool for emissions reductions.
Table 6-19 Summary of IIDAPT “best practices” in ITS for air quality in five US cities

<table>
<thead>
<tr>
<th>IIDAPT</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ATSAC/ATCS in LA</td>
<td>The Automated Traffic Surveillance and Control (ATSAC) system has undergone continual enhancements since the 1980s, allowing the addition of capabilities for traffic control, and more recently for transit signal priority. The Adaptive Traffic Control System (ATCS) is the latest software upgrade to ATSAC, developed in-house, with automated adjustment of signal timings in response to real-time traffic conditions. There is also cooperation with Metro’s for transit signal priority for the Blue Line light rail. The ATSAC system has received several awards for innovation, including an award from the US DOE’s 1995 National Awards Program for Energy Efficiency and Renewable Energy. Studies of air quality impacts have shown clear benefits, but to date there does not appear to be adaptation of the system specifically to air quality outcomes. Some proposals were made, but never fully implemented, to manage traffic in real-time using monitored CO levels and other emissions. Important expansions of the system (Wilmington, Harbor-Gateway) are funded with CMAQ. See trafficinfo.lacity.org/html/atsac_1.html</td>
</tr>
<tr>
<td>RCTSS in Houston</td>
<td>Through cooperation between Metro and the City of Houston, signal hardware is being upgraded, also to include signal priority, as well as interconnected back to TranStar facility for centralized control and monitoring. The project is funded through CMAQ, and is included by the MPO as a TCM in Houston’s air quality plan.</td>
</tr>
<tr>
<td>Universal fare system in LA</td>
<td>CMAQ funding is supporting the multi-agency deployment of a universal fare payment system for transit. The project leader is Metro, but a number of transit agencies in LA county are involved in deployment to increase ridership through more seamless travel. This will cover nearly all major transit service operators of subway, light rail, bus and rapid transit in LA county.</td>
</tr>
<tr>
<td>HOT lane in Houston</td>
<td>This program is an extension of Houston’s HOV and ridesharing program. Through cooperation between Metro, TxDOT, and the Harris County Toll Authority, Houston implemented two of the country’s first managed lanes for carpools, vanpools, minivan pools, and buses. There is also cooperation from H-GAC through the management of the Commute Solutions program for ridematching. Only 2+ carpools (no SOVs) can access HOV lane for a toll. 3+ carpools access the lanes free. Extensive assessment has been done to maintain levels of service, but no evidence yet of adaptation to improve emissions outcomes.</td>
</tr>
<tr>
<td>Ozone Alert! on VMS in Tulsa</td>
<td>In anticipation of possibly exceeding the air quality standards in the early 1990s, Tulsa City/County Health, ODEQ, INCOG and ODOT organized an Ozone Alert! program. Agencies implement temporary measures to reduce emissions only on days predicted to have high pollution levels (which are infrequent). VMS are used to alert the public, and to encourage alternate modes of travel, off-peak travel, or telecommuting. This is a core part of Tulsa’s Clean Air Program. This program was recognized and highlighted by the EPA. See <a href="http://www.ozonealert.com">www.ozonealert.com</a>.</td>
</tr>
<tr>
<td>Multi-modal information in LA</td>
<td>The innovation in this system is the consolidation of information from a variety of motorized and non-motorized modes, presenting users with a unified and consistent interface (<a href="http://www.commutesmart.info">www.commutesmart.info</a>) for accessing traffic conditions, transit schedule and real-time information (where available), transit and bicycle trip planning, instant carpooling and other rideshare match information. Cooperation between LA, Orange, Riverside, San Bernardino and Ventura counties.</td>
</tr>
<tr>
<td>Rideshare support in LA</td>
<td>The database for Ridematch.info (also accessible via <a href="http://www.commutesmart.info">www.commutesmart.info</a>) in the LA region has more than a quarter of a million registered commuters. Web access information has been included as a TCM, and many rideshare activities have been funded through CMAQ. There has been innovation on the technical side with provision of real-time matching of carpools and online information on seat availability in existing vanpools. There has been cooperation for this program between the counties of LA, Orange, Riverside, San Bernardino and Ventura.</td>
</tr>
</tbody>
</table>
It is illustrative that these best practices have some weakness in common, that leave us short of our ideal IIDAPT description. First, there is little evidence of adaptation of technologies in response to new information. Once technologies are deployed based in part on their air quality benefits, those benefits are typically taken for granted. Little follow up occurs. For those technologies that are more certain to have a positive influence, such as technologies supporting more ridesharing or increases transit use, there is little assessment of their effectiveness. For example, from Table 6-18, agencies seem to be relatively convinced that rideshare databases and online ride-matching services are helpful. Yet, there have apparently not been many assessments of how much those measures can actually help, and how further promotion of those services, can change regional VMT and reduce emissions. Although cities are increasingly deploying technologies for ITS-based traffic flow improvements in a number of cities, little headway has been made in addressing the issue of induced travel, despite the fact that through CMAQ, the emissions reductions benefits of these technologies are supposedly being measured in each case.

Second, although there must be approval by the air quality agencies, there is little direct involvement of air quality agencies in the deployment and operations of any of these innovations. Involvement by the air quality agencies has typically been more on the analytical and planning side, in terms of supporting the measurement of CMAQ emission reductions or incorporation of TCMs with ITS into the state air quality plan. Los Angeles took an interesting approach, in the formation of The Partnership, which was created by the region’s MPO (SCAG) and air quality district (SCAQMD) in 1995. A different example would be that of Tulsa, where the Oklahoma Department of Environmental Quality is involved in calling the Ozone Alerts and the communication and coordination that is required to operate this program. It is not, however, entirely clear from the cases what the effect would be if air quality agencies did have more active involvement in the design, deployment, and active measurement of the air quality impacts of ITS technologies. On the one hand, it could push agencies to seek more air quality benefits and perhaps lead to new innovations in this area. On the other hand, it could also have a negative impact on innovation, by increasing the complexity of implementation of ITS technologies for air quality benefits. The air quality agencies could actually encumber those transportation agencies that are trying to deploy ITS in a way that achieves mobility and air quality benefits.

Finally, harking back to our discussion of energy and emissions ITS technologies in Chapter 2, we find that there is no integration of technologies to provide real-time information on emissions and concentrations of pollutants. The proposal by the City of Los Angeles to incorporate carbon monoxide sensors to measure concentrations, and correlate those to traffic flows, was the only example of possible movement in this direction. Again, this relates to the point raised above, in that it is unsure what the outcome would be of greater air quality agency involvement. It could leverage their air quality monitoring capabilities in order to integrate monitoring of pollutant concentrations into transportation system management. Yet, this example from Los Angeles indicates that it was actually the transportation agency that was moving toward real-time monitoring of concentration levels, not the air quality agency.
6.4.3 Revisiting Conformity and CMAQ

The above discussions lead us to assess the role of the transportation conformity framework and the CMAQ program in supporting these types of innovations. We have implicitly and explicitly discussed these programs in earlier sections (particularly Section 6.3), when discussing the role problem severity and dedicated or “slack” resources. However, we will identify some specific points here.

From the viewpoint of stimulating innovation with ITS technologies for air quality improvements, the regulatory framework of transportation conformity does seem to work. Transportation conformity—by linking transportation investment decisions to the attainment of air quality standards—determines the “severity” of the problem perceived by transportation and air quality agencies. A non-attainment designation and the related requirements for the implementation of Transportation Control Measures (TCMs), have also caused transportation agencies to begin to assess their ITS technologies from the standpoint of their potential air quality benefits as TCMs, leading to some interesting innovations in this area.

Conformity and CMAQ provide the “stick and carrots” for managing the transportation system with ITS in a way that meets mobility and air quality goals. Therefore, conformity requirements and CMAQ funding together provided the combination of problem severity (as a motivator) and dedicated resources (as a motivator and enabler) for innovative strategies to reduce mobile source emissions. According to our theoretical framework, these are important conditions for innovation. They are working to move ITS deployments in the direction of air quality improvements, although as our discussion of the “best of” of ITS for air quality mentioned, we are still far from our ideal for IIDAPT.

From the discussion in Section 6.3, we also saw that it is extremely important to keep the “slack” in dedicated resources. During earlier reauthorizations of ISTEA, many highway and other interests pushed for increasing the “flexibility” of CMAQ funding, stating that the air quality aim was too narrow. However, increasing the “flexibility” would have basically been the death knell for the CMAQ program. As seen most clearly in Boston, and as expressed by many interviewees in Houston and Los Angeles, in the absence of the eligibility requirements for and restrictions on the use of CMAQ, many projects, including many ITS projects, may not have had an accessible funding source in the absence of this protected funding category.

Finally, we had indicated that adaptation of the application of these technologies is still weak. There are still many unresolved assumptions and uncertainties behind the technologies that are deployed for air quality benefits. Furthermore, there are no incentives to modify or adapt ITS deployments in the case that they are found to actually degrade air quality—for example, by increasing traffic speeds to the point where emission rates (grams/mile) are high, or by inducing additional demand for travel in single occupancy vehicles. Therefore, perhaps the biggest weakness of the CMAQ program is that the required ex ante assessment provide very little room from learning—either agencies learning from their own deployments, or learning from the experiences of other agencies. Perhaps most disturbingly, this research highlighted that possibilities for longer term induced demand from ITS-based traffic flow improvements are
generally ignored (or denied). As a result, we may not only be seeing some misuse of the
CMAQ program funding, but setting ITS on a so-called "technological trajectory" that is not
supportive of long-term air quality goals. By getting some overuse of measures aimed at
improving traffic flow and thus facilitating the use of the single occupancy automobile through
supply side measures, we may be undermining or detracting from other efforts to focus on the
demand side of transportation (through pricing and through a broader range of viable alternatives
to the private automobile), which would "shape" ITS technologies to be more compatible with
long-term air quality goals.
6.5 CONCLUSIONS

This chapter tested our theoretical construct for Integrated Innovation, Deployment and Adaptation for Public Technologies, looking at ITS and air quality. Outcomes for IIDAPT were closely predicted by the seven conditions in our framework. We found that problem severity, dedicated resources, and mutual benefits were the best predictors of IIDAPT outcomes. However, we could also use some of our more detailed measures of IIDAPT (average levels, range and intensity) along with cross-case comparison, to identify some areas where the actual and predicted outcomes did not align exactly as anticipated. This pointed us to areas where we could delve deeper into the seven conditions, and assess whether the conditions could be used to explain these outcomes. Indeed, the explanatory power of the theoretical framework proved to be more robust than the predictive power of the theoretical framework. It also allowed us to better define and describe some of our IIDAPT conditions.

In terms of actual experience, we found that metropolitan areas in the US have made some, but still limited, progress in integrating air quality concerns into ITS deployments. Concerns regarding the air quality impacts of ITS are still peripheral for most agencies. Indications are that agencies will focus on the emission reduction possibilities of ITS where it aligns with their interests and priorities for transportation investments, but there has been no fundamental shift in the direction of using ITS to “co-manage” transportation systems and their impacts, in a way that gives real priority to these impacts.

Having developed this theoretical framework, we will now apply it to a different case outside of the US – the Mexico City Metropolitan Area. The purpose will be to apply the model to assess the possibilities for IIDAPT in Mexico, and make recommendations for innovation in ITS in ways that can support air quality and mobility goals in Mexico City. Therefore, while the technology domain is the same – ITS application for achieving air quality benefits – the context is very different. We now turn to the case of Mexico City.
CHAPTER 7. MEXICO CITY: CASE HISTORY, ANALYSIS AND RECOMMENDATIONS
7.1 INTRODUCTION

In the previous chapter, we demonstrated the validity of our theoretical framework for our five US case study cities. Extending this framework to predict outcomes for Integrated Innovation, Deployment and Adaptation of Public Technologies (IIDAPT) and provide policy recommendations to another US city would, in principle, be relatively straightforward, given that most cities would have analogies with one or more of the cases already examined. Therefore, in this chapter, we look at the extension of the framework to Mexico City.

7.1.1 Motivation for Extension to Mexico City

In this chapter, we will take our theory one step further, testing the theory and assessing its ability to provide useful policy and technology recommendations to a non-US city, regarding how to deploy ITS in a way that is supportive of air quality objectives. Applying the results of the US case studies to a non-US case clearly provides some additional challenges. To begin, the institutional and regulatory context at the federal, state and local level will be substantially different. In the US, the federal regulatory context included the 1990 Clean Air Act Amendments (CAAA) and 1991 Intermodal Surface Transportation Efficiency Act (ISTEA), with important federal funding programs such as the Congestion Mitigation and Air Quality (CMAQ) program, and the requirement for metropolitan transportation plans to conform with the intent and goals of state air quality plans. Similar federal legislation and federal-aid funding programs do not yet exist in Mexico. In addition, the institutional arrangements at the metropolitan level are quite different in Mexico City, with no US-style Metropolitan Planning Organization (MPO) with equivalent functions and powers. Finally, although the process of quantifying actual IIDAPT outcomes for ITS and air quality is relatively transferable from one context to another (and possibly from one technology domain to another), we anticipate that the process of measuring the conditions for predicted IIDAPT outcomes will be quite different in a non-US city.

However, there are also important insights to be gained from applying this framework to the case of Mexico City. First, it will test whether the seven conditions described for the IIDAPT framework are broadly applicable. For example, in the US case studies, the condition of "dedicated resources" was essentially equivalent to having funding from the CMAQ program, while "problem severity" equaled non-attainment, or the danger of falling into non-attainment with national air quality standards. Applying this framework to Mexico City will force us to consider how those conditions could be redefined or replicated in a non-US context. Second, it will test the robustness of the theoretical framework, to see if it can be applied outside of the US. As noted earlier, local context is important in shaping IIDAPT outcomes. Comparing the case of Mexico City to the US cities, we will see if the influence of local context swamps out the

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307 Where "new" cases would differ most would be in the "local context." While context does play an important role in shaping IIDAPT outcomes, for example, in terms of the diversity of IIDAPT applications and the modal orientation (i.e., transit, traffic), the average level and intensity of IIDAPT can be largely predicted by the seven conditions.

308 As outlined in Chapter 4.

309 As described in Chapter 6.
influence of the seven conditions we have described and defined, or, if they can continue to be
predictors of IIDAPT outcomes.

7.1.2 Mexico City Fieldwork

The fieldwork for the Mexico City case differed from the fieldwork undertaken for the US case studies. Starting in the fall of 1999, the author was a research assistant with the Integrated Program on Urban, Regional and Global Air Pollution: The Mexico City Case, an interdisciplinary research program based at MIT. As part of this research project, the author attended a number of conferences on air pollution in Mexico City, and also conducted individual and group interviews with public and private sector organizations and individuals. The author completed a series of interviews with planners and analysts from public sector agencies regarding general transportation and air quality planning and management in the Mexico City Metropolitan Area (MCMA) in December 2002 and January 2003. Between August 2003 and December of 2005, the author was in residence in Mexico City, working on a number of projects, including a Conflict Assessment of Mexico City Metropolitan Air Quality Management (Rosan, Susskind et al. 2005). The author also collaborated on a project lead by the Institute for Transportation and Development Policy (ITDP) and the Mexican Center for Environmental Law (CEMDA) which analyzed possible pathways to legislative reform for more integrated transportation and air quality planning. In terms of ITS deployments, the author interviewed individuals involved in ITS for traffic management, as well as for public transportation, including both the subway system (Metro) and Metrobús rapid bus corridor, and with researchers from the Mexican Transportation Institute (IMT). Additional information on ITS deployment was also gained from personal communications with local and international participants at Intertraffic Mexico, a national ITS trade show/exposition and conference held in October 2004. Therefore, the material for the Mexico City case was gathered from a greater number of sources, and during a much longer period of time, than for the US cases cities.

7.1.3 Structure of Analysis

The structure of the chapter is as follows. First, in Section 7.2, we will describe the federal-level institutional and regulatory context for ITS, transportation, and air quality policy in Mexico, highlighting the differences with the US. Then, in Section 7.3, we will follow the same general outline used in Chapter 5 to describe the US case study cities, to look at the history of air quality management efforts, ITS deployment trends, and then focus on the links between ITS and air quality in Mexico City. Next, in Section 7.4, we will apply our theory of the seven factors that determine the level of Integrated Innovation, Deployment and Adaptation of Public Technologies (IIDAPT). This theory was developed and described in Chapter 4, and was then tested against five cities in the US in Chapter 6, in order to see if predicted levels of IIDAPT (according to the seven conditions) coincided with actual IIDAPT levels observed during the case study visits. Therefore, in this section, we will test the theory for Mexico City, with the core difference being that we will be examining a non-US case.

This effort included the CEMDA/ITDP International Seminar: Toward the Reform of Transportation and Air Quality Planning held in Mexico City in June 2004. See www.itdp.org/pub.html for the background papers.
Finally, in Section 7.5, we will develop a set of technology and policy recommendations for Mexico City. This will be in two parts. First, drawing upon the lessons from Chapters 2 and 3, which examined the state of knowledge regarding the air quality impacts of different ITS technologies, we will suggest specific technologies that could be deployed and adapted to the Mexico City context to advance both mobility and air quality goals. We will also draw upon some best practices in using ITS for air quality as observed in our five US case study cities. However, as we learned from the US case study analysis in Chapter 6, technologies that have “win-win” benefits are not always deployed. On one hand, sometimes the seven conditions for IIDAPT do not align in ways that will produce “good” IIDAPT outcomes. The problem may not be severe enough to spur innovation, there may not be adequate resources and/or capacity to innovate, or there may simply be too many organizations to effectively cooperate in the deployment of technologies to serve multiple policy goals. On the other hand, even where the conditions seem “right” for IIDAPT, outcomes may be sub-optimal due to the interaction of organizational interests. In this case, apparent mutual benefits – promoting both air quality and mobility goals – may not always be mutual benefits from the perspective of the agencies involved. Therefore, in the second part of Section 7.5, we will distill lessons from the testing of the theory, in order to identify possible changes that could be made to improve IIDAPT outcomes in Mexico. This highlights the policy relevance of this research. Based on the results of the previous chapter, and the application of the theory to Mexico City, we will be able to identify possible policy interventions to improve the use of ITS in ways that better support air quality objectives in Mexico City.
7.2 ITS AND AIR QUALITY POLICY AT THE FEDERAL LEVEL IN MEXICO

Before focusing on the case of the Mexico City Metropolitan Area, we will first look at the policies at the federal level in Mexico regarding both ITS deployment and air quality management. This will provide a comparative analysis to the US, where federal legislation, through the 1990 Clean Air Act Amendments and the 1991 Intermodal Surface Transportation Efficiency Act, created incentives and provided funding for ITS, and held long-term metropolitan transportation planning more strictly accountable for its impact on air quality. In Mexico, the relationships and roles for the federal, state and local governments have been quite different, but have also been changing substantially over the past several decades.

Although the theoretical framework, developed in Chapter 4, focuses largely on the local conditions for Integrated Innovation, Deployment, and Assessment of Public Technologies (IIDAPT), it is important to outline the relevant federal institutional and political trends that have a bearing on ITS deployment, general transportation planning, and air quality management. We will first review the trends toward greater democratization and decentralization in Mexico, and its impact on the federal-local relationship. We will then look at recent federal-level policy toward ITS, and the federal framework for air quality regulation and transportation planning.

7.2.1 Democratization and Decentralization

In order to understand the institutional and political context in which transportation and air quality decisions are made in Mexico, and in the Mexico City Metropolitan Area, we must first look at two broader trends that have happened at the national level. First, is the democratization of Mexican politics. After 71 years of unbroken political hegemony by the Institutional Revolutionary Party (Partido Revolucionario Institucional, or PRI), marked by uncontested elections and electoral fraud, Mexico now has a truly democratic system. Although the PRI’s formerly unchallenged power started to slip when it began to concede losses in state and municipal elections across Mexico, it was not until the 2000 election of the current President Vicente Fox, from the conservative National Action Party (Partido de Acción Nacional, or PAN), that a more pluralist political structure seemed to finally have emerged. Indeed, the July 2, 2006 elections proved to be an extremely tight contest between the two non-PRI candidates, Felipe Calderón, from the PAN, and Andrés Manuel López Obrador, from the more leftist (Partido Revolucionario Democrático, or PRD). The candidate for the PRI, Roberto Madrazo, held a distant third place. In fact, even during the campaigning, he did not appear to be a likely contender for the presidency.

Although a changeover in party for the executive branch did not occur at the federal level until 2000, at the local level, a new party took office in the Federal District for the first time in 1997 (see Table 7-1). Until that date, the executive branch for the Federal District was a presidential-

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311 According to the Federal Electoral Institute (IFE), Felipe Calderón (PAN) won the 2006 presidential election with 35.89% of the vote, compared to 35.31% for Andrés Manuel López Obrador, a difference of approximately 243,000 votes (www.eluniversal.com.mx accessed July 6, 2006). At the time of the submission of this thesis, the PRD candidate, López Obrador, was continuing to challenge the results of the election pushing for a recount based on allegations of possible fraud.
appointed, non-elected “mayor” for what was then called the Department of the Federal District (*Departamento del Distrito Federal*). According to this arrangement, in place since 1941 and lasting until 1997, the mayor would be directly responsible for carrying out the president’s policy regarding local administration of the Federal District. Therefore, there was both a democratization of Mexico, in terms of the PRI ceding the presidency to another political party, as well as a democratization of Mexico City, where not only was the mayor no longer a political appointee of the president, but was also, as it happens, elected from a competing party. The first elections for a Mayor of the DF, in July 1997, were won by Cuauhtémoc Cárdenas from the PRD. This mayor would now have greater participation in law making, fiscal budgeting, and general administration of city services.

Democratization was also occurring with the local legislative branch for the DF. Before the 1990s, local representatives had only limited functions for making recommendations and proposals, or served as “watchdogs” for DF expenditures and policy. During the 1990s, the Legislative Assembly of the Federal District (ALDF) was created, with greater control over approving local spending and power to enact laws and regulations for the DF. In the 1997 elections, the majority of the seats were filled by representatives of the left-wing PRD, the same party as the mayor, winning 38 of 66 seats (Nava Escudero 2001, p 116).

**Table 7-1 Timeline for national and DF administrations since 1988**

<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
<th>President of Mexico</th>
<th>Mayor of Federal District</th>
</tr>
</thead>
</table>

Therefore, closely connected with the political democratization that was occurring, were the steps toward administrative decentralization, in which regulatory and administrative powers were shifted from the federal government to the state and local levels of government. Decentralization of financial resources has also occurred, with the federal government reducing its direct investment in and financial support to Mexico City. Federal taxes are still redistributed to the states and DF, but these governments now have to depend more on locally-generated revenues such as taxes, fines and fees, as well as greater participation from the private sector (Nava Escudero 2001, p 116; Gakenheimer, Molina et al. 2002, p 270). Many scholars have debated the impact of this on city management (Nava Escudero 2001, p 197). On the one hand, greater accountability to the local electorate should improve the effectiveness of local administrations.
On the other hand, the devolution of powers to local entities, and increasing competition between political parties, could also lead to greater difficulties in coordination between the DF and the surrounding municipalities of the State of Mexico. These issues will be revisited below.

7.2.2 Federal ITS Policy

Federal transportation policy in Mexico has largely focused on federal highway construction and maintenance. To date, there has been very little development of what one could call an official ITS policy or ITS program at the federal level in Mexico. In comparison to the US, where there were strong private and public sector interests in promoting the application of advanced technologies, particularly those from the defense sector, to surface transportation systems, there was no such equivalent pressures in Mexico. As in other developing country cities, there are relatively few local suppliers of ITS applications. Therefore, there has not been a similar push from the local ITS industry to promote ITS solutions in Mexico. However, there has been a growing demand for ITS applications. At the federal level, the organization with the longest involvement in ITS is CAPUFE (Campos y Puentes Federales de Ingresos y Servicios Conexos), the federal toll road operator with primary responsibility for tolled roads and bridges throughout Mexico. CAPUFE operates approximately 160 toll plazas throughout Mexico. In urban areas, there has been increasing demand for technologies to manage traffic flows, such as CCTV, traffic signal control, VMS, and ITS applications to improve transit, the deployment of which will be described more in detail below.

An ITS Mexico Committee was formed in 1999, including members from the Secretariat of Transportation and CAPUFE, and others. The formation of ITS Mexico, a similar organization to ITS America, represents an important step toward a national ITS policy, with much of the committee’s focus on the development of an ITS architecture, as will be discussed below. The need to organize national ITS efforts is something that has been advocated by ITS America for several years, according to a representative from ITS America’s International Relations program. However, the Secretariat of Communications and Transportation (Secretaria de Comunicaciones y Transporte, or SCT) has still not taken a highly active role in promoting ITS either at the federal or local level. ITS has apparently not become a priority area for the SCT. For example, in the SCT’s annual report on activities, the term ITS is only briefly mentioned twice, once with respect to the development of a national architecture (Secretaria de Comunicaciones y Transportes (SCT) 2005).

7.2.2.1 Developing an ITS Architecture

To a large extent, the development of the Mexican ITS Architecture has been prodded and shaped by interests north of the border. ITS America, the US Trade and Development Agency

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313 See www.capufe.gob.mx.
315 Personal communication, ITS America, International Relations, October 28, 2004, Mexico City.
(USTDA), officials from both the FHWA and FTA, as well as US suppliers of ITS products and services have demonstrated substantial interest in promoting ITS solutions in Mexico, as well as an ITS Architecture and standards compatible with those in the US. The motivations for this are straightforward, "U.S. companies face significant competition from European and other Latin American supplies.... [and] it is clear that significant benefits will accrue to U.S. companies if the architecture developed under the auspices of the U.S. Department of Transportation (DOT) is chosen" (Federal Transit Administration 2000, p 29).

In 2003, the US TDA provided a grant to fund the development of an ITS Architecture for Mexico. The winning proposal was from Wilbur Smith Associates, a US-based consulting firm, which would work with the Mexican consulting firm, Suma Sinergia, on the development of the ITS Architecture and recommendations for ITS solutions. Much of the focus of the development of the ITS Architecture has been on improving and expanding ITS for intercity highways, particularly, for electronic toll collection, and for commercial vehicle operations, particularly issues related to control of freight movements. However, in early presentations on the development of the ITS Architecture, they also recognized the important differences between the US and Mexico, particularly the much higher levels of use of public transportation in Mexico (Wilbur Smith Associates 2004). Although the focus was on the development of a National ITS Architecture, the project also envisioned state- and municipal-level architectures that would be compatible with the national architecture, with the idea that this would enable better integration of ITS applications at the state and local level as well.

7.2.2.2 National Architecture and Local Deployments

Nevertheless, there are signs at the local level of a lack of awareness or even indifference to these national efforts to promote ITS, and in particular, the development of the Mexican ITS Architecture. For example, at Intertraffic 2004 (ITS Exposition and Trade Show), held in Mexico City in October of 2004, several speakers were invited both from industry and local transportation agencies in Mexico City currently involved in ITS deployment. Many of the local government representatives failed to show up for their presentation. Those that did show up, often appeared only for the duration of their own talk, without spending significant amounts of time meeting with ITS industry representations or visiting booths in the trade show. In fact, a representative from ITS America expressed frustration with the fact that at these events, few if any local decisionmakers really participated.

While at the federal level there seems to be slowly growing interest in ITS and recognition of the need for integrated ITS services, local decisionmakers seem to be deploying their ITS applications with little interaction with and concern for these national-level initiatives. This is not to say that there is no local interest in ITS. On the contrary, there are emerging applications in the three largest cities – Mexico City, Guadalajara, Monterrey – as well as smaller cities such as Jalapa, and many of the border cities – Ciudad Juarez, Tijuana, Nuevo Laredo – that have to deal with heavy flows of freight and passenger traffic across the US-Mexican border. However,

there is an apparent disconnect between the national ITS efforts – or what could be called an emerging national ITS policy – and local ITS efforts. While the national ITS efforts are largely motivated by suppliers and their representatives (through ITS America and the US TDA), the local ITS efforts are motivated by the needs of local decisionmakers dealing with traffic and transit management.

7.2.3 Federal Air Quality Regulation and Transportation System Planning

This section will describe the institutional and legislative structure for air quality regulation and transportation system planning in Mexico, drawing upon comparisons with the transportation conformity requirements in the US.

7.2.3.1 Federal Air Quality Standards

Similar to the US, the federal government is responsible for the development of national ambient air quality standards. These standards, established by the federal Secretariat of the Environment and Natural Resources (Secretaría de Medio Ambiente y Recursos Naturales, or Semarnat), are very similar to those of the US in terms of the maximum concentrations, the averaging periods – including a 1-hour and 8-hour standard for ozone – and the number of exceedances “allowed” in a given year (see Table 7-2). In fact, the 1-hour ozone standard in Mexico is slightly more stringent than the US standard of 0.12 ppm. For all pollutants, with the exception of ozone, the concentrations can be exceeded once a year. Again, for ozone, the Mexican 1-hour standard is more stringent in that there are no “allowed” exceedances, compared to the US where there can be three exceedances during a three-year period. Yet, as will be seen in Section 7.3.2.3, the ozone standard is exceeded the vast majority of the days of the year, even more so than in Los Angeles in the 1970s and 1980s. The question is: what happens when the standards (shown in Table 7-2) are exceeded in a metropolitan area? As will be discussed below, there is little actual enforcement of these ambient air quality standards.

Table 7-2 National ambient air quality standards in Mexico

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Maximum Concentrations</th>
<th>Averaging Period</th>
<th>Allowed Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>$O_3$</td>
<td>0.11 ppm</td>
<td>1 hour</td>
<td>None</td>
</tr>
<tr>
<td>CO</td>
<td>0.08 ppm</td>
<td>8 hour</td>
<td>Five times a year</td>
</tr>
<tr>
<td>SO$_2$</td>
<td>11 ppm</td>
<td>8 hour</td>
<td>Once a year</td>
</tr>
<tr>
<td>NO$_2$</td>
<td>0.13 ppm</td>
<td>24 hour</td>
<td>Once a year</td>
</tr>
<tr>
<td>PM$_{10}$</td>
<td>0.21 ppm</td>
<td>1 hour</td>
<td>Once a year</td>
</tr>
<tr>
<td>TSP*</td>
<td>150 μg/m$^3$</td>
<td>24 hour</td>
<td>Once a year</td>
</tr>
<tr>
<td></td>
<td>260 μg/m$^3$</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: (Instituto Nacional de Ecología (INE) 2003, p 2)

Although these are the official national ambient air quality standards for Mexico, perhaps the more pertinent pollution limits – from the viewpoint of concrete actions taken to avoid exceeding these limits – are those set as part of the “contingency” program. These contingency levels, shown in Table 7-3, are set at more than 2.5 times the health-based standard for ozone, and 2 times the health-based standard for PM$_{10}$ listed in Table 7-2 above.
Table 7-3 Levels for activation and deactivation of a Phase I contingency event

<table>
<thead>
<tr>
<th>Contingencies for:</th>
<th>Activation</th>
<th>Deactivation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ozone</td>
<td>Levels reach more than 0.28 ppm</td>
<td>Levels reach fall below 0.21 ppm</td>
</tr>
<tr>
<td>( PM_{10} )</td>
<td>Levels reach more than 300 ( \mu g/m^3 )</td>
<td>Levels reach fall below 250 ( \mu g/m^3 )</td>
</tr>
<tr>
<td>Both</td>
<td>Simultaneous levels more than 0.263 ppm ozone and 200 ( \mu g/m^3 ) of ( PM_{10} )</td>
<td>Ozone levels less than 0.208 ppm</td>
</tr>
</tbody>
</table>

Source: (Secretaría de Medio Ambiente del Distrito Federal 2005, p 3)

The purpose of the environmental contingency program is to warn the public that dangerously levels of ozone and/or particulate matter (\( PM_{10} \)) are predicted for the following day, in order to reduce exposure by avoiding outdoor activities, particularly for children, the elderly, and other sensitive populations, and to take actions that will reduce emissions. The program is divided into “pre-contingencies” and “Phase I” and “Phase II” contingencies, which step up the restrictions on certain activities, such as outdoor burning, asphalt production, road-maintenance, vehicle circulation, and industrial and power production (Molina and Molina 2002, p 330).

While bringing down average pollution levels to the health-based air quality standards is the objective of air quality plans and programs in Mexico City, the contingency program has also fostered a strong focus on episodic controls to reduce peak pollution levels (contingency limits) that are acutely dangerous to public health. Therefore, there are long-term programs to reduce average ozone levels, as well as episodic controls to reduce the peak ozone levels, reflecting two tiers of standards. From a practical standpoint, however, the creation of contingencies inadvertently made these higher concentration limits the de facto air quality standards from the viewpoint of the general public. The public and many policymakers focus more on the number of contingency days, than on the number of days above the ambient air quality standards. Because the majority of the number of days of the year are above the ambient standards (shown in Table 7-2), the public and policymakers focus less on this metric of air quality. In comparison, in the US the focus is clearly on the national ambient air quality standards, because of the implications of falling into non-attainment status. In cities where there are ozone alert programs – requiring additional but episodic controls and encouraging voluntary actions to reduce peak ozone levels – those alerts are aimed at avoiding exceedances of the national ambient air quality standards.

7.2.3.2 Regulatory Framework Linking Air Quality and Transportation Planning

As this discussion indicates, while the standards themselves are quite similar, there are important differences in the enforcement of these standards. In terms of actual enforcement, there is very little connection between the air quality standards and the local/metropolitan transportation plans and programs. There are no concrete legal or fiscal penalties for projects or plans that lead to more frequent violations of the air quality norms, comparing, for example, a build/no-build scenario for transportation infrastructure. Transportation plans and programs are not required to systematically assess long-term air quality outcomes, in a way that would be similar to conformity determinations in the US, or even Strategic Environmental Assessments in the
European Union. As a result, the primary environmental “constraint” on transportation projects and plans, is the need to carry out an environmental impact assessment (EIA), as will be discussed below. In this sense, the official federal standards for air quality, are almost entirely disconnected from the transportation planning process. A transportation plan can raise air pollution far above the official norms, with no repercussions from the legal or financial standpoint, as long as the individual projects within that plan meet the threshold of no serious environmental damage, as documented through the EIA process.

In the US, air quality management is a local and state responsibility. While the federal government provides guidance, sometimes highly detailed guidance and requirements for what measures should be considered (such as “reasonably available control measures”), it does not directly participate in air quality management. Intervention by the federal government in the actual air quality planning process, has however been wielded as a threat to the state and metropolitan areas. If an adequate state implementation plan is not submitted to the EPA, the EPA has the authority to step in and promulgate and enforce a federal implementation plan for air quality (Garrett and Wachs 1996, p 11).

The experience in the MCMA, however, has been quite different. During its time as a “Department” of the Federal District, when mayors were appointed by the president and not directly elected, the federal government, through Semarnat, had the authority and responsibility to develop air quality plans for the MCMA. While many implementation and enforcement activities were carried out by various Mexico City mayors and their administrations, these were non-elected officials, having been appointed by the president until 1997. According to Nava Escudero, even the “new 1996 air quality programme for the MZMC that enhances and updates the 1990 PICCA is a good example of continuous central intervention,” going on to explain that Semarnat was still the central player in air quality planning and management even in the late 1990s (Nava Escudero 2001, p 196). Yet, the 1990s have also seen a substantial devolution of power to the Federal District, meaning that Semarnat is increasingly stepping out of the air quality planning and management process, giving greater authority over to the Secretariat of the Environment in the DF (Secretaría de Medio Ambiente, or SMA), Secretariat of Ecology in the State of Mexico (SE) and the coordinating body between them, the Metropolitan Environmental Commission (CAM). The more recent air quality plans, have begun to break with the tradition of heavy federal intervention, as the local environmental agencies have begun to assert themselves to a greater extent. For example, the SMA has pressured the federal

317 Strategic environmental assessments (SEA) require a more comprehensive environmental impact assessment of an entire program or plan.
318 Until 2000, Semarnat was referred to as Semarnap, with the last “p” (for Pesca) in the acronym referring to the inclusion of fisheries. These responsibilities were transferred to the Secretariat of Agriculture.
319 The first program for air quality was adopted in 1990, the Integrated Program for the Control of Atmospheric Pollution (Programa Integral para el Control de la Contaminación Atmosférica, or PICCA). The update to that program was the Program to Improve Air Quality in the Valley of Mexico (Programa para Mejorar la Calidad del Aire en el Valle de México, or Proaire). The current Proaire is from 2002 to 2010.
320 Because Semarnat is a member of the CAM, it will continue to have an important role in air quality management in the MCMA. However, the presidency of the CAM, is a rotating two-year position between the DF and State of Mexico, meaning that the DF and EM are the primary players.
government, particularly on the issue of fuel quality and vehicle emissions standards, arguing that they cannot clean the air in the MCMA without greater improvements in reducing vehicle emission rates. Another important step in this direction was the transformation of the DF’s legislative assembly, which can now enact legislation (equivalent to state laws), where before, it simply had consultative and oversight functions. While there has been decentralization of air quality management in the Federal District, the process has also led to some “blurring of responsibilities” regarding the division of responsibilities between the central government and local governments (Nava Escudero 2001, p 196). This has been clear in some recent environmental impact assessments of large transportation infrastructure projects in Mexico City.

### 7.2.3.3 Transportation System Evaluation in Mexico

Federal legislation in Mexico requires the use of Environmental Impact Assessments (EIA) to assess possible environmental damages of projects under federal jurisdiction. The federal requirements are outlined in the Rulemaking for Environmental Impact (Reglamento de Impacto Ambiental), which describes in greater specificity the EIA requirements contained in the General Law of Ecological Equilibrium and Environmental Protection (Ley General de Equilibrio Ecológico y la Protección al Ambiente) (Ezcurra 1995). This framework also applies at the federal and state level, since the states, including the Federal District, have similar laws for environmental protection and regulations for the specific EIA requirements. For the Federal District, EIAs are required under the Environmental Law of the Federal District (Ley Ambiental del Distrito Federal) and again specified in the Rulemaking for Environmental Impact (Reglamento de Impacto Ambiental) (CESPEDES 2002).

For transportation infrastructure projects, the jurisdiction over a specific project usually hinges on whether the projects modifies what is considered federal infrastructure or not. For example, a highway project crossing two separate states would be considered under federal domain for the submission of an environmental impact statement. However, at times this distinction can be vague. For example, for a transportation facility spanning two or more states, if the transportation expansion project itself is contained within a single state, the EIA will fall solely under that state’s jurisdiction. Therefore, only one state reviews/approves the EIA, even if the project has important upstream and downstream impacts that affect contiguous states, or if it has an impact on regional environmental quality.

The Environmental Impact Assessment process, both in the legislation and in practice, has several important drawbacks which limit their effectiveness in promoting environmental protection, including:

- Lack of institutional capability to effectively review EIA, in terms of the quantity of EIAs needed to be processed, and the ability to review their technical and scientific validity and robustness (Ezcurra 1995; Bojórquez-Tapia and García 1998; Ortega-Rubio, Salinas-Zavala et al. 2001).\(^{321}\)

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\(^{321}\) Ezcurra (1995) provides a brief and critical analysis of the overall process of EIA in Mexico, having 16 years of experience in developing EIA and two years working with the federal government in the Institute of Ecology (INE). Ortega-Rubio and other focus on the decisions of the staff of environmental authorities, and how they make...
• Political and economic pressures to approve projects (Ortega-Rubio, Salinas-Zavala et al. 2001). In some cases, the “defendant” (project promoter and developer of the EIA) and the “judge” (environmental authority or reviewer of the EIA) have been one and the same (CESPEDES 2002).

• Coupled with the pressures to review large volumes of EIAs, there are additional pressures and delays associated with the current process of public consultation. As a result, public consultation is often avoided or minimized (Ezcurra 1995).

Environmental Impact Assessments are one of the few possible mechanisms for guarding against the environmental deterioration resulting from major infrastructure projects, albeit with the serious limitations described above. Yet, EIA only applies at the project level. Looking at the broader system-level impacts, of say, a comprehensive program or plan containing multiple individual projects, there is no mechanism for evaluation and avoidance or mitigation of these system impacts. Therefore, in terms of transportation plans or programs, there are basically no planning or evaluation requirements to ensure that a transportation plan or program will improve, or at least, not worsen, air quality.

7.2.3.4 Moving toward a Conformity-type Framework?

Several interrelated issues came to the forefront with the critiques of the environmental impact assessment undertaken for the recent project that would “double-deck” two urban highways in the Federal District. First, there is no regulatory mechanism to make individual projects “accountable” for their long-term impact on regional air quality. Second, and on a similar note, there is no regulatory mechanism to link EIA to the national standards for ambient air quality. Third, the process of developing and reviewing EIA is highly flawed and subject to analytical errors and political pressures. Fourth, there are issues of jurisdiction with projects that have broader impacts that may affect more than one state, which could call for federal involvement in the review of environmental impacts, or involvement of all affected states. Finally, there is no mechanisms for reviewing the overall impact of a comprehensive transportation plan or program on the environment or on air quality.

Both local and international non-governmental organizations, such as the Mexican Center for Environmental Law (CEMDA) and the Institute for Transportation and Development Policy (ITDP), have looked at legislative changes that would address these issues. In 2004, a workshop was held with local and national decisionmakers and international experts from the US, Europe, and South America, assessing possible pathways for legislative reform in the area of transportation planning and air quality management. One legislative/institutional model that was evaluated was the applying a US-type framework for transportation conformity in Mexico, in which entire transportation plans would be analyzed and evaluated for their long-term impact on decisions regarding the “level” or rigor of environmental impact assessment required for a given project. Bojórquez-Tapia and Garcia focus on the contents of the environmental impact statements submitted by promoters of highway projects. Together, these articles provide a good overview of the various facets of EIA, the production of the EIA, and the evaluation of the EIA, and the role of EIA as a mechanism for public consultation.

322 The project itself will be discussed in depth below.
air quality. Another legislative/institutional model proposed was the use of Strategic Environmental Assessment (SEA), which builds upon the model of project-level Environmental Impact Assessments. SEA moves the assessment up earlier in the planning stage, in order to consider a broader range of alternatives, and considers the systemic impact of multiple projects that may form a program or plan for transportation investment. This approach has used more extensively in the European Union. As of the writing of this thesis, no regulatory changes have been made to the existing legislative framework in Mexico at either the national or local level. As a result, it will continue to be difficult, if not impossible, to successfully challenge major transportation projects (either through the EIA process or through litigation of projects by citizen groups or NGOs) based on their regional air quality impacts. In contrast, in the US, transportation conformity has been a powerful regulatory lever to challenge projects or require additional projects to mitigate environmental impacts. We will later discuss the implications this may have for the use of ITS for air quality purposes in Mexico City.
7.3 TRANSPORTATION AND AIR QUALITY IN THE MEXICO MEGACITY

Now that we have described the federal-level context for transportation and air quality management, we will now turn to Mexico City.

7.3.1 Background

7.3.1.1 The City

Since the 1950's, Mexico City has undergone substantial transformations as it made the transition from a medium-large city, with about 3 million inhabitants in 1950, to being one of the largest metropolitan agglomerations in the world by the 1990s. These urban transformations were not only of scale. Another important shift was the increasing urbanization of the municipalities in the State of Mexico (Estado de México, EM), which surrounds the Federal District (Distrito Federal, DF) to the north, east and west. By the year 2000, the population of the urbanized EM municipalities, for the first time, outnumbered the population of the DF, as can be seen in Figure 7-1. Indeed, population in the Federal District remained relatively stable, around eight to nine million residents between 1980 and 2000, while in the State of Mexico, growth experienced annual growth rates of 6% on average between 1970 and 2000. In the 1970s, during its period of highest growth, the State of Mexico grew by 312,000 inhabitants on average each year (Lezama, Favela et al. 2002).

Figure 7-1 Population growth of the Mexico City Metropolitan Area (MCMA)

![Population growth graph]

Source: (Lezama, Favela et al. 2002, pp 64-65)

The geographic expanse of this growth can also be seen in Figure 7-2. The map gives a sense of the layout of the basin of the MCMA, with most of the older urbanized areas covering the largely flat surface of the basin floor (at an altitude of 2,240 meters above sea level). Expansion toward the west has been checked by the mountains; however, there is still considerable

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323 As a comparison, Denver, Colorado (the "mile-high city") lies at an altitude of just over 1,600 meters.
expansion toward the east, and more importantly, toward the north of the central city, where it has literally enveloped some of the smaller volcanoes. The population of the MCMA continues to grow, albeit at slower rates than seen in previous decades. However, with falling household sizes, trends toward greater urban sprawl in the EM – and even reaching into other states such as the State of Hidalgo to the northeast – are expected to continue.

Figure 7-2 Growth in urban area of the Mexico City Metropolitan Area (1970-2000)

The MCMA is also marked by high income inequalities. While the upper 10% of the population has 40% of the wealth, the lower 50% of the population possesses only 19% of the wealth (Gakenheimer 2003). This inequality manifests itself in land use – with large swaths of “irregular” settlements contrasting with large gated communities – and perhaps more starkly in transportation choices. Clearly, the private automobile is the overwhelming mode of choice for higher-income families, whereas public transportation, whether the Metro, buses or smaller colectivos, often carry a social stigma, perceived as a transportation for the lower classes.

7.3.1.2 Transportation

Mexico City’s public transportation system is a highly complex network of government operated subway, light rail, trolley buses, regular bus service, and privately operated bus and jitney service. More recently, the first Bus Rapid Transit line was introduced to the mix of transit services in Mexico City, with the inauguration of Metrobús, a 19-km BRT corridor along Insurgentes Avenue, one of the most important and longest avenues in the MCMA. However, the dominant modes in the MCMA are the microbuses (also referred to as minibuses) and
colectivos. The change in modal split for the MCMA shown in Figure 7-3 – widely cited by researchers and policymakers in reports, articles, books and official documents – highlights the remarkable growth in the use of microbus and colectivo services, largely at the expense of the government-operated bus service.

Figure 7-3 Estimated modal split for the MCMA (1986-2000)

Source: (Secretaría de Transporte y Vialidad del Distrito Federal (Setravi) 2002)

Indeed, the evolution of the modal split in the Mexico City Metropolitan Area shows a clear decline in the use of high capacity modes such as the Metro, Light Rail and Trolleybuses, as well as in medium capacity modes such as the buses. Low-medium capacity modes, such as the minibuses and colectivos, were increasingly taking up those trips, with an extraordinary growth from 6% to 55% of all motorized trips over a 14-year period. Indeed, policymakers and researchers repeatedly refer this graph as representative of the major trends in transportation in Mexico City from the late 1980s to the early 2000s. However, this graph from the Integrated Program for Transportation and Roadways, using data from Setravi, appears to be incongruent with respect to the number of trips in private automobiles. Motorization and VMT in Mexico City has grown substantially in recent years, with growth in income per capita increasing the buying power of families. Coupled with increasing options for credit and financing, large segments of the population that previously would not have had the income or savings to purchase a vehicle, now have one or more family cars. This has also led to an increased demand from a larger proportion of the population for improved roadway infrastructure. Taken together, the continued growth in population, falling household sizes, decentralization of urban development, and increased possibilities for auto ownership create a strong impetus behind in the burgeoning

324 The term colectivos refers to the origin of informal public transportation as “fixed-route collective taxis” which were primarily sedans. As the importance of this informal public transportation mode grew, the size of the vehicles also increased, first to vans, then to minibuses, and more recently to buses.
economic demand for private vehicles, and as a result, political demand for the expansion of the MCMA’s roadway infrastructure and the mitigation of traffic congestion.

There are five main highway access points linking the Federal District to surrounding cities – Queretaro, Pachuca, Puebla, Cuernavaca, and Toluca – most of which have both a free and tolled highway. The non-tolled highway usually has substantially longer travel times and is often less safe. Indeed, as seen Figure 7-4, the tolled and free highways may closely overlap (such as the 95 to Cuernavaca and 190 to Puebla). In addition to being important links between the MCMA and the rest of the nation, they have also been the locus of new urban development.

Figure 7-4 Roadway network for the MCMA

Source: www.mapquest.com

Because of the large share of trips still undertaken in public transportation, coupled with the growing demand for private automobiles, both public transit and congestion mitigation are critical issues with a high level of attention by the public, therefore creating pressures on elected officials and government agencies to address both issues. Under these pressures, the early 2000s saw the implementation of two highly visible and often controversial transportation projects: the double-decking or “Second Story” (Segundo Piso) over the urban highway Periférico, and the Metrobús rapid bus corridor on Insurgentes Avenue. We will discuss these two projects, and their implications for mobility and air quality in greater depth in Sections 7.3.2.3 and 7.4.3.
7.3.1.3 Institutions

The institutional structure in the Mexico City Metropolitan Area (MCMA) is not only complex, but has also been undergoing major changes due to the trends of decentralization and democratization described above. This has fundamentally shifted the political and administrative base of the Federal District. While formerly governed from the federal level, the DF is now the equivalent of a state-level entity, with local elections for the Jefe de Gobierno (who is often referred to as the Mayor, although the position is analogous to a state governor). Decisions regarding transportation investment and policy, as well as decisions on air quality management, are now more local issues. We will discuss three levels of government entities, and their areas of policy intervention: federal, state (i.e., the Federal District and State of Mexico), and metropolitan. The Federal District is included as the equivalent of a state-level government. For simplicity, we do not include the municipal governments for the State of Mexico (municipios) or the Federal District (delegaciones). There are 16 delegaciones in the DF, and 37 municipios in the State of Mexico that are included in what is commonly considered to be the Mexico City Metropolitan Area (Lezama, Favela et al. 2002, p 64-65). While the municipality governments are of growing importance as they find their footing in a more decentralized and democratic environment, for the moment, they do not yet have a critical role in either air quality management or the deployment of ITS, which are the focus of this thesis.

- Federal Institutions

At the federal level, responsibility for environmental protection and regulation and the management of natural resources falls under the cabinet-level Secretariat of the Environment and National Resources (Secretaría de Medio Ambiente y Recursos Naturales, or Semarnat). With respect to air quality, there are two autonomous institutions of importance supporting Semarnat, the National Institute of Ecology (Instituto Nacional de Ecología, or INE) and the Attorney General for Environmental Protection (Procuraduría Federal de Protección al Ambiente, or Profepa). For transportation, the Secretariat of Communications and Transportation (Secretaría de Comunicaciones y Transportes, or SCT) is responsible for interstate highway construction and maintenance. Along with the shift in public finances from the federal level to the local level, the SCT has shifted responsibility for managing both highway and transit infrastructure (such as the Metro). The SCT has to a large extent withdrawn from major investment decisions in the MCMA, and therefore has limited influence over metropolitan transportation policy. Under the federal-level SCT, the Mexican Transportation Institute (Instituto Mexicano del Transporte, or IMT) is responsible for transportation-related research, diffusion of scientific and technical information, and capacity building. IMT has only been working in the area of ITS since 1998, and has not significantly expanded its internal ITS program. Banobras is the infrastructure development bank.

- Metropolitan Institutions

As seen in Table 7-4, the responsibilities for air quality management and transportation management, planning and operations in the MCMA are characterized by substantial fragmentation and overlap. Table 7-4 also highlights how coordination for metropolitan-level
mobile-source policies require vertical cooperation – between federal and state/local agencies – horizontal cooperation – between transportation and air quality agencies, and within the transportation agencies, cooperation between planning, construction, operations and enforcement.

Table 7-4 Government agencies and areas/sub-areas of intervention

<table>
<thead>
<tr>
<th>Government Entity</th>
<th>Area</th>
<th>Sub-areas</th>
<th>Area</th>
<th>Sub-areas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Federal government</td>
<td>Semarnat</td>
<td>Regulation, Air quality standards, Fuel and vehicle standards</td>
<td>SCT</td>
<td>Planning, analysis, construction</td>
</tr>
<tr>
<td></td>
<td>INE</td>
<td>Research/analysis</td>
<td>Banobras</td>
<td>Financing</td>
</tr>
<tr>
<td></td>
<td>Profepa</td>
<td>Inspection/enforcement of industrial sources, citizen complaints</td>
<td>IMT</td>
<td>Research/testing/analysis</td>
</tr>
<tr>
<td>Federal District (DF)</td>
<td>SMA</td>
<td>Inspection/Maintenance program, Planning/modeling/data collection, Enforcement</td>
<td>Setravi</td>
<td>Planning/modeling/data collection, Public transport concessions</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Public Works and Services</td>
<td>Road construction and maintenance</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Metro</td>
<td>Planning, subway construction, subway service provision</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Public Safety</td>
<td>Traffic operations, Enforcement/control</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>STE</td>
<td>Light rail/trolley service</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>RTP</td>
<td>Bus service</td>
</tr>
<tr>
<td>State of Mexico (EM)</td>
<td>SE</td>
<td>Inspection/Maintenance program, Planning/modeling/data collection, Enforcement</td>
<td>SC</td>
<td>Road construction and maintenance</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>ST</td>
<td>Public transport concessions, traffic operations</td>
</tr>
<tr>
<td>Metropolitan Institutions</td>
<td>CAM</td>
<td>Regulation/analysis</td>
<td>Cometravi</td>
<td>Consultative</td>
</tr>
</tbody>
</table>

Source: Updated and adapted from Tables 6.21 and 6.22 in (Gakenheimer, Molina et al. 2002).

Overcoming vertical and horizontal fragmentation of responsibilities is highly difficult. In terms of metropolitan-level strategies for the environment, there has been some success through the Metropolitan Environmental Commission (Comisión Ambiental Metropolitana, or CAM). Yet, there has been much less progress in coordination of transportation-related activities through the Metropolitan Transportation and Roadways Commission (Comisión Metropolitana de Transporte y Vialidades, or Cometravi). While CAM has had access to independent financial resources, and has some executive and regulatory powers, Cometravi has been substantially more

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325 The acronyms used in this table are described in the text before and after this figure.
limited in its ability to implement policies (Molina and Molina 2002, p 269). In the area of regional transportation planning, there are often several concurrent planning activities taking place at the federal level, in the DF, and in the State of Mexico, with little interaction or coordination between those plans. According to a planner at the Secretariat for Transportation and Roadways (Secretaría de Transportes y Vialidades, or Setravi), the local plans for regional development and land use are supposed to take into consideration national level plans for major infrastructure and other plans. However, in reality, local plans end at jurisdictional borders and do not encompass the larger metropolitan area, which leads to one set of plans and programs encompassing the metropolitan population living in the DF, and another set for plans and programs for the population residing in the surrounding municipalities in the State of Mexico.

The political competition between the Federal District and State of Mexico also exacerbates efforts at metropolitan coordination. In the early campaigning by 2006 candidates to the presidency, the Governor of the State of Mexico, Arturo Montiel, was vying for the nomination of the PRI, while the Mayor of the Federal District, Andrés Manuel López Obrador, was competing for (and eventually secured) the nomination as the PRD’s presidential candidate. Many observers felt that the greater political aspirations of elected officials (and their parties) have undermined efforts toward metropolitan-level coordination. However, there are also deeper issues creating barriers to metropolitan-level coordination, such as the disparity in wealth (government finances and average income per capita) between the DF and State of Mexico, and differences in the relative training of personnel in public sector agencies and level of personnel turnover. There are also differences due to the internal politics of the State of Mexico, in that the center of political power for the state is in its capital of Toluca, to the west of the urbanized municipalities that are considered part of the Metropolitan Zone of the Valley of Mexico (Iracheta Cenecorta 2004).

- **State-level Institutions**

Because we are looking at integrated innovation for air quality and mobility, we will be looking more closely at the cooperation between transportation and air quality agencies, leaving to other researchers the issues of metropolitan coordination, which is another entire topic in its own right. We will consider the case of the Federal District more extensively than the surrounding municipalities of the State of Mexico, in part because the DF is further ahead in the area of both air quality and ITS deployment than the State of Mexico. Therefore, for this chapter, we will be primarily be discussing the Secretariat of the Environment (Secretaría de Medio Ambiente, or SMA), Secretariat of Transportation and Roadways (Secretaría de Transportes y Vialidades, or Setravi), Secretariat of Public Security (Secretaría de Seguridad Pública, or SSP), Secretariat of Public Works and Services (Secretaría de Obras y Servicios Públicos, or SOS), the Metro (subway system), STE (light rail and trolleybus service provider), and RTP (bus service provider). In the State of Mexico, there is the Secretary of Ecology (Secretaría de Ecología, or

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326 Setravi, Personal communication, December 2003.
327 We will use the terms Metropolitan Zone of the Valley of Mexico (MZVM) and the Mexico City Metropolitan Area (MCMA) somewhat interchangeably. Because Mexico City, or Ciudad de Mexico, historically refers to the four central delegations of the Federal District, observers from the State of Mexico prefer the former term (MZVM).
SE) and the Secretariats of Communications (for roadways) and Transportation (for public transportation) (Secretaria de Comunicaciones and Secretaria de Transporte, or SC and ST).

Again, looking at Table 7-4 above, we can see that there is substantially more fragmentation between transportation agencies than for environmental agencies in the DF. In particular, there is fragmentation of planning and analysis (Setravi), management of private sector transit operators (Setravi), traffic operations and enforcement (SSP), construction and maintenance (Public Works), and government-owned transit operations (RTP, STE, and Metro). Yet, because these organizations are all under the mandate of the Mayor (Jefe de Gobierno) of the DF, there are, in principle, greater possibilities for coordination through the office of the Mayor. Indeed, some observers have referred to the current governance structure in Mexico City as “a highly centralized, city-wide and mayor-headed local authority” (Nava Escudero 2001, p 112). Therefore, we find that while the responsibilities for transportation and air quality, as defined by the legislation, are dispersed across a number of different agencies in the DF, with somewhat unclear and overlapping responsibilities, at the same time, there are possibilities for substantial mayoral intervention for issues that deal directly and indirectly with various agencies’ mandates. We will discuss these issues of cooperation and fragmentation under the current administration (2000-2006), as it related to issues of transportation and air quality. Specifically, we will consider what the impact has been of the particular forms of interagency “cooperation” that have emerged.

- Non-Governmental and International Organizations

For the case of Mexico City, international organizations should also be considered, both in terms of their impacts on the development of ITS, as well as the impacts on the development of transportation and environmental policies and programs. As discussed above, ITS America and ITS vendors from the US and elsewhere have taken an interest in the Mexican market for ITS products. In the area of transportation and air quality, groups from the World Bank have been involved through financial and technical support to policymakers and decisionmakers in Mexico City for many years. More recently, groups such as EMBARQ, part of the World Resources Institute, have also promoted environmentally-friendly transportation options in Mexico, collaborating through local NGOs such as the Center for Sustainable Transport. These international institutions have provided financial and technical support in ways that would be analogous to the support received by local governments in the US from the FHWA or FTA.

Research groups from institutions and universities outside of Mexico in collaboration with national universities, such as UNAM (National Autonomous University of Mexico) and ITESM (Monterrey Institute of Technology and Higher Studies), have also brought a wealth of scientific and technical support to support air quality management efforts. The Mexico City Program at MIT, 328 which also included researchers from Harvard, Boston University and collaboration with other academic and research institutions, was initiated in 1999 by Dr. Mario Molina, a Chemistry Noble Laureate in 1995 for his work in stratospheric ozone depletion. This project, which lasted at MIT from 1999 to 2004 attempted to provide an integrated assessment of the air quality

328 The author was a research assistant at MIT for the Mexico City Project between 1999 to 2003.
problem and multi-sector solutions that were technically, economically, and politically feasible. Other researchers have questioned the ultimate influence on air quality policies, suggesting that a more collaborative process for stakeholder input into the scientific and technical modeling of air quality improvement options, would have lead to better outcomes (Mostashari 2005). However, in practice, the influence may not have worked directly through the technical reports or lists of recommendations produced by the research teams, but rather via the public statements and declarations made by Mario Molina himself, and his personal interactions and influence with key decisionmakers.329 The Molina Center for Strategic Studies on Energy and the Environment was established in Mexico City in 2004 to continue to provide scientific and technical input to decisionmakers.

7.3.2 Air Quality History

Unfortunately for public health, the geography and meteorology of the air basin of the Mexico City Metropolitan Area is highly favorable to ozone. The high altitude of Mexico City, mentioned earlier, results in intense solar radiation that drives the photochemical process of ozone formation. The surrounding mountains also effectively trap pollutants within the basin – particularly when coupled with thermal inversions during the winter months with little precipitation – ozone can reach very dangerous levels. In addition, “predominant wind patterns in the afternoon often transport pollutants from the industrial area northeast of the city to the city center and the residential areas southwest of the city” (Molina, Molina et al. 2002, p 141).

7.3.2.1 Sources

In terms of ozone precursors, Mexico City has been found to have very high ratios of VOC to NOx, based on the 1998 emissions inventory (Molina, Molina et al. 2002). This has also been confirmed in the more recent (2002) emissions inventory, shown in Figure 7-5. VOC emissions are extremely high, even compared to cities such as Los Angeles. Area sources are the predominant source, with commercial and domestic solvent use, and the distribution, installation, and use of liquefied petroleum gas (LPG)330 representing some of the biggest culprits (Secretaria de Medio Ambiente del Distrito Federal 2002). This ratio of VOC to NOx suggests that ozone formation is NOx-sensitive or NOx-limited, meaning that reductions of NOx are a more effective strategy than VOC controls. Indeed, much of the modeling work has been in reconciling the emissions inventory with observed ozone levels, since VOC (as well as CO) has usually been substantially underestimated in emissions inventories.331

329 Indeed, during interviews that were undertaken with a wide range of stakeholder and decisionmakers for metropolitan air quality management – part of a Conflict Assessment lead by researchers at MIT – many pointed to Molina as a highly credible and respected public figure on environmental issues. He was also cited as perhaps the only person that could break the impasse on the metropolitan coordination on air quality management.  
330 Releases of VOC primarily occur as leaks from improper installation, and from unburned hydrocarbons during the use of LPG.  
331 In order for modeled ozone levels to fit with measured concentrations, researchers often have to multiply VOC emissions (from the official emissions inventory) by a factor of 3 West, J. J., M. A. Zavala, et al. (2004). “Modeling ozone photochemistry and evaluation of hydrocarbon emissions in the Mexico City metropolitan area.” Journal of Geophysical Research 109.
Looking at the breakdown of NOx emissions by point, area and mobile sources for anthropogenic emissions, mobile sources greatly outweigh area and point sources in the MCMA. Within the category of mobile sources (see Table 7-5), emissions from private automobiles are approximately one-third of total mobile source emissions. Although private automobiles have lower emissions rates (on a per vehicle, not per passenger, basis), the fleet is over 2.7 million (again, see Table 7-5).\(^{332}\) Looking only at the category of passenger transportation, and thus excluding vehicles for goods movements – i.e. tractor-trailers, the second largest mobile source category – the contribution of private automobiles to NOx is even more evident. Taxis are another important source, with nearly 20% of mobile sources emissions, due to the intensive use of these vehicles.

**Figure 7-5 Emissions Inventory for the Mexico City Metropolitan Area**

*metric tonnes per day*\(^{333}\)

![Emissions Inventory](chart.png)

*Source: (Secretaria de Medio Ambiente del Distrito Federal 2002, Table 3.3.1)*

Taking into account both the importance of NOx controls, and the fact that mobile sources are the principal source of NOx emissions, actions aimed at reducing mobile source emissions will continue to be critical to improving air quality in the MCMA. On average, the private automobile fleet is substantially newer and cleaner compared to earlier years. However, approximately 34% of gasoline vehicles in the MCMA still do not have emissions control systems, according to the SMA, meaning that they will generate a disproportionately large share of emissions (Secretaria de Medio Ambiente del Distrito Federal 2002). This suggests that high emitters continue to be highly problematic in the MCMA.

\(^{332}\) These vehicle fleet numbers are for 2002, taking into account new vehicles sales, the private automobile fleet could now be somewhere between 3.5 or even up 4 million. See Figure 7-6 for data on annual vehicle sales.

\(^{333}\) For comparison with the emission inventories for the US, which use (short) tons (2,000 lbs), Mexico uses (metric) tonnes (1,000 kg). Thus, 1 tonne = 1.1 tons.
Table 7-5 Mobile source NOx emissions by vehicle category

<table>
<thead>
<tr>
<th>Source</th>
<th>Number of vehicles</th>
<th>annual emissions (metric tons/day)</th>
<th>% of mobile source emissions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Private automobiles</td>
<td>2,712,262</td>
<td>145</td>
<td>33.8</td>
</tr>
<tr>
<td>Taxis</td>
<td>115,974</td>
<td>41</td>
<td>19.6</td>
</tr>
<tr>
<td>Combis</td>
<td>19,485</td>
<td>11</td>
<td>2.5</td>
</tr>
<tr>
<td>Microbuses</td>
<td>32,236</td>
<td>27</td>
<td>6.3</td>
</tr>
<tr>
<td>Pick-up trucks</td>
<td>175,021</td>
<td>30</td>
<td>7.1</td>
</tr>
<tr>
<td>Vehicles less than 3 tons</td>
<td>273,396</td>
<td>65</td>
<td>15.3</td>
</tr>
<tr>
<td>Tractor-trailers</td>
<td>75,571</td>
<td>67</td>
<td>15.6</td>
</tr>
<tr>
<td>Buses</td>
<td>30,683</td>
<td>26</td>
<td>6.0</td>
</tr>
<tr>
<td>Vehicles greater than 3 tons</td>
<td>59,225</td>
<td>16</td>
<td>3.7</td>
</tr>
<tr>
<td>Motorcycles</td>
<td>94,437</td>
<td>1</td>
<td>0.2</td>
</tr>
<tr>
<td><strong>ALL</strong></td>
<td><strong>3,588,290</strong></td>
<td><strong>429 tons</strong></td>
<td><strong>100.0%</strong></td>
</tr>
</tbody>
</table>

Source: (Secretaria de Medio Ambiente del Distrito Federal 2002, Table 4.3.8)

Furthermore, as has happened in the US and elsewhere, the pace of reductions in the emission rates of individual vehicles (grams per kilometer traveled) through cleaner vehicles and fuels, is counterbalanced by increases in vehicle kilometers traveled (VKT). This increase in VKT is spurred not only by growth in individual trip making and trip distances, particularly as the city continues to expand, but also by the rapid motorization of the population. For example, in the MCMA alone, for the past several years, over 300,000 new vehicles have been added to the fleet each year.\(^{334}\) This had led to a substantial shift from public transportation to travel by private automobile.

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\(^{334}\) However, this only looks at additions to the private vehicle fleet, and does not include vehicles that are subtracted from the fleet, i.e. vehicles that are no longer used or are re-sold outside of the MCMA. Furthermore, these older vehicles that are no longer circulating the MCMA, are likely to be among the highest emitters, assuming that they are older and possibly malfunctioning vehicles.
7.3.2.2 Actions

Most of the transportation-related actions undertaken to improve air quality have been via: (1) improvements in vehicle emission equipment and fuels, (2) improved inspection and maintenance programs, (3) mandatory driving restrictions, (4) renovation of the public transportation fleet through new vehicle purchases in government-operated services (RTP), and scrappage/incentive programs for turnover of the private-owned and operated fleet of microbuses, and (5) expansion of relatively "non-polluting" modes such as the Metro, light rail, and trolleybuses. Vehicle and fuel improvements have taken place through regulation by Semarnat and investments in improved refining by the state-owned petroleum company, Petróleos Mexicanos (Pemex). Most of the reductions in emissions have been attributed to the introduction of cleaner vehicles and fuels; specifically, unleaded gasoline, catalytic converters, I/M programs, US Tier 1 vehicle emission standards, and on-board diagnostic (OBD) systems (Gakenheimer, Molina et al. 2002, p 278-9). At the local level, substantial efforts and funds have been directed toward promoting turnover in the fleet of taxis and colectivos. For example, in 2001, a program was created by the DF to buy and scrap pre-1990 microbuses, financing the

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335 MCMA sales are calculated as percentage of national sales as given in Aoki, C. (2002). Technological Change for Environmental Improvement: The Case of the Mexican Automobile Sector. Doctoral Thesis in Technology, Management and Policy. Engineering Systems Division. Cambridge, MA, Massachusetts Institute of Technology. The average MCMA share of national sales from 1993-1999 (42%) was used to estimate MCMA vehicle sales between 2000 and 2006. The sharp drop in sales in 1995 was a response to the economic crisis that occurred that year with devaluation of the peso. Monthly average sales (January through March) were used to estimate annual sales for the rest of 2006. Because November and December generally have substantially higher sales figures, this estimate for 2006 is probably conservative.

336 These are "non-polluting" only in the local sense, in that they are electric modes that do not have emissions from the vehicles themselves. Power generation has largely been moved outside of the Mexico City air basin.
purchase of new diesel buses with credits up to 100,000 Mexican pesos (Gakenheimer, Molina et al. 2002, p 279).

On the planning front, the Federal District began to more seriously integrate transportation and environmental planning through two documents: the 1995 transportation program, Programa Integral de Transporte y Vialidad (PITV), and the 1996 air quality program, Programa para Mejorar la Calidad del Aire en el Valle de México (Proaire). These two documents were updated again with the PITV 2001-2006 and Proaire for 2002-2010. Comparing these documents to the planning and programming structure in the US, these “programs” fall somewhere between a plan and a program. It lacks the long-term planning horizon and continuity of most planning documents in the US, for example. On the other hand, there is little specificity in most of the project descriptions, particularly in project funding sources. Therefore, the PITV and Proaire often take on the characteristic of a “wish-list” for transportation and air quality projects. With no clear prioritization scheme included within the programs, the projects that will actually be funded and implemented often depend upon the preferences of elected officials when developing and approving annual spending budgets. As a result, much of the planning document’s original balance between modes, and between operations-based improvements and capital investments found in the programs, is later lost in the political wrangling over the budgeting process. While the more recent plan contemplates expansion of public transit service, it also includes substantial expansion of highway capacity. As noted by Nava Escudero, referring to the PITV (transportation program) and Proaire (air quality management program) of the late 1990s, these plans were intended to “re-arrange and considerably increase the use of public transportation, but not without continuing to favour private vehicles” (Nava Escudero 2001).

- **Transportation Control Measures (Demand Management)**

In terms of transportation control measures (TCMs) – whether demand management or supply management measures – there has been substantially less activity. On the demand management side, there have been no major programs initiated to decrease vehicle use and/or increase vehicle occupancy in private vehicles through ridesharing, HOV lanes, compressed work weeks, employer-based vanpools, or congestion pricing. Some argue that certain demand management measures currently used in the US, such as carpooling, may be poorly suited to the context of developing country cities (Vasconcellos 2001, p 288). For example, in the MCMA, transit is still the dominant mode share, albeit one that is losing ground. Because automobile trips are still officially considered to be a minority of trips (as shown in Figure 7-3), there has not been as much discussion around increasing the occupancy levels of trips in private vehicles, as in the US where travel in private autos is the norm. In addition, combining origins and destinations of travelers requires substantial information and surveillance capabilities, which might not exist except in very large enterprises in developing country cities (Vasconcellos 2001, p 288). For many demand management measures, enforcement of those measures would be extremely

337 20% is the official figure, although experts at the Center for Sustainable Transportation in Mexico City estimate that the mode split has probably evolved toward a much higher share of trips in private vehicles.

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difficult. For example, there is no uniformity in or regulatory control over parking pricing and/or availability and a lack of resources to enforce on-street parking restrictions.\footnote{Indeed, in addition to on-street parking, there is often “on-sidewalk” parking. Enforcement of parking in many high-demand streets, particularly in commercial areas, is essentially controlled by the informal sector franeleros. These are individuals that “help” drivers find available on-street parking spaces for a “tip” in return (often having previously blocked-off those spaces with obstacles).}

Public transport expansion, as a demand management measure, is included in both Proaire and PITV documents, but seems to be aimed more at maintaining mode share (taking into account growth in overall travel), rather than attracting people back from private automobiles. Therefore, air quality management efforts related to public transit have focused more on introducing cleaner vehicles both into the government-operated fleet, through direct purchases, and into the privately-operated fleet, through credits for new vehicle purchases with scrappage of older units.

There have been more recent efforts to promote non-motorized transportation, in particular, through the creation of bicycle routes. These investments have to a large extent been undertaken in response to pressures from environmental groups criticizing large infrastructure projects that favor the automobile. For example, when environmental and other citizen groups challenged the social and environmental sustainability of projects such as the double-decking of two major urban highways, pushing instead for transportation “alternatives” such as better public transit, bikeways and more pedestrian-friendly facilities, the administration’s response was to incorporate the “alternatives” into the package of highway infrastructure investments.\footnote{“Promueven ciclopistas en el Pais (Promoting bike routes in the nation),” Reforma, November 11, 2003. See also www.fimevic.df.gob.mx.} It is unclear whether there is a more strategic plan by the public sector for developing a comprehensive bicycle infrastructure, and if bicycle corridors will continue to be built if NGO pressures do subside, or if this was a one-time mitigation measure to placate opponents of highway expansion projects.\footnote{Alberto Acosta, “Piden apoyo vecinal para nueva ciclovía (Seeking neighborhood support for new bikeway),” Reforma, April 24, 2006.}

\textit{Hoy No Circula} (HNC), Mexico City’s “no-drive day” according to license plate numbers and vehicle age, is probably the most well-known demand management measure for both congestion mitigation and air quality improvements by reducing VMT. In theory, the measure is simple. According the last number on the license plate, vehicle owners were assigned a day of the week in which their vehicle cannot circulate during the day (Monday to Friday). Because it operated five days of the week, each day, two license plate numbers would be banned, thus restricting 20\% of the private vehicle fleet. In 1995, the measures were strengthened to further restrict circulation of older vehicles during contingencies. Eventually, as the program was linked to the inspection and maintenance program and modified to provide incentives for turnover in the private vehicle fleet, a more complex scheme for exemptions developed. Newer vehicles (1993 model years and newer) equipped with catalytic converters would be allowed to circulate every day of the week, thus encouraging people to buy newer vehicles instead of facing the inconvenience of HNC. Therefore, the measure began both as an air quality measure and a
congestion mitigation measure, taking 20% of the vehicle fleet out of circulation once a week. With tighter circulation restrictions for older vehicles, and exemptions for newer vehicles, the program would be more specifically directed to the most polluting vehicles, and provide incentives for turnover in the fleet. However, with exemptions from HNC, the congestion mitigation benefits would begin to diminish rapidly. Air quality benefits also began to lose ground as the size of the vehicle fleet (albeit a cleaner fleet) circulating in the MCMA, continued to grow. HNC has also been widely cited as a case of unintended consequences in policy implementation, in that it was also believed to have spurred the market for used vehicles, as a back-up vehicle for restricted days, as a way to avoid the driving restriction (Eskeland and Feyzioglu 1997; Orsunal and Gautam 1997).341

Policymakers in the DF have not fully accepted the analyses suggesting that there was an increase in the purchase (or retaining) of second-hand cars for the day the primary car is banned. Yet, the deterioration of the effectiveness of the policy has lead to revisions of the program. However, there has been no serious contemplation by decisionmakers of fundamentally different demand management measures, such as congestion pricing. London broke with earlier paradigms that suggested that no elected official would be willing to accept the political risks of implementing congestion pricing, and that no public would accept it. Discussions have taken place in academic circles regarding the possibility of congestion pricing in Mexico City (Mahendra 2004). Some consider congestion pricing a smoother form of demand management than HNC, in that people would have the option to pay to drive, rather than the more inflexible driving bans.342

In terms of ridesharing, one could consider the smaller colectivo taxis (such as sedans or minivans) as a market-driven form of ridesharing (or more specifically, vanpooling), in which the vehicle’s owner/operator is paid by the riders. However, this would represent a much different dynamic from the US, where ridesharing shifts drivers from single occupancy vehicles to carpool or vanpools. The colectivo service in the MCMA is more characteristic of a niche market for public transportation where regular bus service does not reach, and where residents to not have access to a private vehicle. Although the transportation officials generally do not hold informal public transportation services such as colectivos, combis, and microbuses in high esteem, some analysts outside of Mexico, have pointed to the benefits of this informal service as an adaptive response to the land use, transportation network and transportation demands of the population. In fact, Cervero lauds the “free-enterprise paratransit sector... superbly tailored to the region’s spread-out landscape” (Cervero 2002, p 379).

* Transportation Control Measures (Supply Management)

Looking at supply management measures for emission reductions – traffic flow improvements through traffic signalization, incident management, traveler information, intersection

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341 See Appendix B of Molina and Molina (2002) for a good discussion and analysis of the evolution of Hoy No Circula and its impacts.

342 Discussion during the Joint Seminar of the International Union of Air Pollution Prevention and Environmental Protection Association (IUAPPA) and Integrated Program on Urban, Regional and Global Air Pollution (IPURGAP), January 22-23, 2004, Mexico City.
improvements – there has been little done. As described below, the Secretariat of Public Security (SSP) for the DF has been expanding its network of computerized signals connected back to the Traffic Control Center. However, that effort has not been considered a measure for air quality improvements. In fact, although Proaire has a measure for the modernization of metropolitan traffic management systems, it does not include the SSP as one of the actors involved. Instead, it lists Setravi as the primary actors for those improvements, even though Setravi does not have an active role in traffic signalization and management.

**Summary**

The focus of mobile source emission reduction strategies has primarily been on improved vehicles and fuels. Given the age of the vehicle fleets, and number of high emitters, and potential for further reductions with available emission control equipment, and lower sulfur fuels, this is indeed an effective strategy for emission reductions. However, where efforts have lagged is in more aggressive measures to affect the evolution of the mode share in the MCMA. Again, the transportation and air quality problem in Mexico City is often defined by decisionmakers by the shift in mode share toward lower capacity modes, as illustrated in the widely-referenced Figure 7-3, and the growth in the use of the private automobile. Despite this rhetoric, the expansion of public transit, although considered and included as a number of measures in Proaire, has not been a prominent measure for air quality improvements. Only more recently, with the new Metrobús project, have transportation and air quality planners begun to make more serious and substantiated claims for changing the mode share by luring people from their cars to public transportation. In the evaluation of the emissions benefits of Metrobús, credit was taken for vehicle replacements, improved traffic flows, as well as mode shifts from private autos to Metrobús. Demand management strategies are not common, with the exception of Hoy No Circula, which has had mixed success as a measure targeted at air quality improvements and congestion mitigation. Further behind are traffic flow improvements or other transportation supply measures as emission reduction strategies.

7.3.2.3 **Issues**

Although air quality in the MCMA is still far from acceptable according to Mexican air quality standards, the progress that has been made in improving air quality has nearly made air quality management a victim of its own success. Atmospheric concentrations of SO₂, CO and lead fell substantially during the 1990s. Concentrations of ozone and particulate matter also fell, although not as dramatically. From the perspective of the public, the air quality crisis seems to have passed. Since the late 1990s, there have been very few “contingencies” which, as explained above, are triggered by extremely high pollution events (for example, when ozone exceeds 0.282 ppm). The contingency program includes several measures to be taken during such pollution events, including additional HNC driving restrictions and reductions in industrial production and power plant operations. While in 1991, there were up to 72 contingencies, there have been no contingencies since 2002 (see Figure 7-7). Therefore, with contingency levels of ozone and

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343 Indeed, as will be discussed below, more recently Setravi and the Secretariat of Public Works and Services developed a list of 100 actions to improve traffic flow, none of which consider operational improvements.
PM$_{10}$ pollution now apparently under control, there is a general sense that air quality has been improved to acceptable or at least “bearable” levels.$^{344}$

Figure 7-7  Number of days above 1-hour ozone limit (0.11 ppm) and above Phase I contingency levels for ozone (0.282 ppm)

Despite the public sense that the problem has been abated, according to researchers, ozone and particulate matter “remain pollutants of serious concern, showing only small decreases in concentration during the 1990s” (West, Zavala et al. 2004). As seen in Figure 7-7, the number of day exceeding the 1-hour ozone limit, has not fallen rapidly. With the exception of a “clean” year in 2004, ozone standards have generally been exceeded over 250 days of the year.

During a Conflict Assessment performed in the fall of 2004 and spring of 2005, consisting of interviews with nearly 50 stakeholders from government, the private sector, and NGOs, many interviewees also expressed the sense that there was no longer a sense of crisis. Indeed, more recently, water quality and availability has risen to the forefront as perhaps the new environmental crisis facing the MCMA. Yet, even in the absence of contingencies, unhealthy air quality is still the norm, with one-third of the days of the year above the 1-hour ozone limit of 0.11 ppm. Looking at exceedances of the 1-hour ozone standard since 1989 in Figure 7-7, it is clear that some progress has been made. However, comparing the rate of progress in reducing the number of days above the limit, one can also see that cities such as Los Angeles have made more substantial gains over the same period of time, despite the fact that these cities had already taken important actions to reduce air pollution in the 1970s and 1980s.

$^{344}$ Researchers from UNAM suggest that people have simply become accustomed or resigned to living with irritated eyes, sore throats and infections, and other conditions caused by air pollution. Iván Sosa, “Ahoga a los capitalinos el ozono (Ozone chokes the capital’s residents),” Reforma, February 29, 2004.
Double-decked highways or confined bus corridors?

It is also important to look beyond issues of cleaner fuels and vehicles, and demand management strategies such as HNC, and examine some of the major investments in the MCMA transportation infrastructure. Much of the recent tension in transportation and air quality policy is based in disagreements over the relative share of resources that should be destined to expansion of roadway capacity and expansion of public transportation infrastructure and operation. Therefore, we will discuss two important and highly visible transportation projects that were recently implemented in the Federal District. We consider it appropriate to review these two projects under this section on air quality management, because both of these projects had the interesting and, at times, controversial characteristic that they were headed by the Secretariat of the Environment for the Federal District. Furthermore, both of these projects have the potential to substantially affect long-term air quality, although not necessarily in positive directions.

As mentioned earlier, growing motorization has increased the demand for more infrastructure to accommodate the private automobile, with many officials considering roadway expansion as a viable measure to reduce congestion levels and travel delays. Although previous mayors had also used highly visible capital infrastructure projects as a way to distinguish their administration, the administration of Mayor Andrés Manuel López Obrador (2000-2005) would be marked by an audacious project consisting of double deckeng two of the city’s most important and congested highways – the Periférico (a north-south route) and Viaducto (an east-west route), along with massive interchanges and flyovers. The so-called “Second Stories” (Segundos Pisos) project immediately raised responses from environmental and other NGOs, both locally and internationally, based upon its potential environmental and social impacts, and the possibility for induced demand (CESPEDES 2002). The Mexican Center for Environmental Law (CEMDA) attempted to litigate the project based upon issues of impacts on surrounding homeowners (as there was no clear legal route to challenge the project on environmental grounds). NGOs and public figures critiqued the project on the basis of its air quality impacts, possibilities to induce additional demand, and equity implications of prioritizing the car over public transportation. Despite some signs that the project might be cancelled due to environmental challenges, budgetary constraints, and the dubious results of a public referendum

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345 Technically, the director of these projects is the President of the DF’s Trust Fund for Improvement of Roadways (Fimevic). These “trust funds” are government revenue instruments, generally using public funds, which are designated to very specific purposes and/or projects. Yet, there has been a high level of turnover in this position, while the Secretary of the Environment has been the primary public figure representing this project.

346 For example, Mayor Hank Gonzalez undertook massive road widening projects to create 16 Ejes Viales between 1978-9, a series of wide, one-way avenues, with counterflow lanes for trolleybuses, as well as significant expansion of the Metro. According to Ward, this spending program also provided ample opportunities to “distribute patronage and largesse among his own political supporters” Ward, P. M. (1998). Mexico City: The production and reproduction of an urban environment. Boston, MA, G.K. Hall & Co.

347 Although López Obrador would have been mayor until 2006, he left the position in 2005 to campaign for President of Mexico.
on the project, the first flyover (Distribuidor San Antonio) was built in 2002, followed by the Second Story over Periférico (in the South of the DF).

However, there are also pressures to improve public transportation. Coupled with the deterioration of service quality and the mode shift from larger buses to smaller informal colectivo services, there is a demand for a high quality public transportation system. As the Second Stories were being planned and constructed, progress was also being made on an entirely different project, a dedicated corridor for a bus rapid transit type service along Insurgentes, one of the longest and most important north-south avenues through the city. This Metrobús would consist of a confined corridor in the center lane for exclusive use of articulated buses with boarding platforms at-level with the station, multiple wide doors for entry, pre-paid electronic fare payment for entering the stations, frequent service, new logos, and signage for clear identification of stations along the route. The same critics of the Second Stories were praising efforts to develop a new public transit option that would be implemented at a lower cost than other public transit modes such as the Metro, but with significantly better travel times, comfort and image than regular bus service. For example, the Sub-secretary of Planning and Environmental Policy at the federal-level Secretariat for the Environment and Natural Resources (Semarnat), Fernando Tudela, stated the following:

"Through public works projects favoring the automobile, we could be increasing emissions of greenhouse gases, the cause of climate change. But, if we complement projects that improve roadways with effective public transportation, such as the dedicated bus lanes, many will quit burning gasoline in their cars, and will use a modern public transit system."

The project, called Metrobús, grew out of a collaboration with and the support of international agencies such as the World Bank and EMBARQ, the World Resources Institute’s Center for Transport and Environment, that began in 2002 (Shipper 2004). What is interesting to note, is that the project’s discussion does not focus as much on local air quality, but rather on the impact of transportation in Mexico City on global greenhouse gas emissions, and ability to "sell" those reductions as carbon credits. As noted by two of the participants involved via EMBARQ:

"While restraining greenhouse gases is a critical goal for the world, it is rarely a major factor for or against adopting major reforms in the transport sector beyond those affecting vehicle fuel efficiency and fuel choice…. But the benefits of restrained CO2 emissions should accrue to transport and other projects…. In some instances, verified savings of

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348 There was only a 6.6% voter participation in the referendum. Under a new Law of Citizen Participation (Ley de Participación Ciudadana), these results should have been invalid. “Mexico City Announces Bus Rapid Transit Plans” Sustainable Transport e-update, No. 5. Bulletin of the Institute for Transportation & Development Policy (ITDP). March 2003. Available at: www.itdp.org.

349 Several NGOs such as Participación Ciudadana (Citizen Participation), the Centro Mexicano de Derecho Ambiental (CEMDA), and ITDP, strongly supported the Metrobús project. However, several environmental groups opposed the Metrobús, protesting the decision to use Insurgentes as the first corridor, because it would mean that a large number of trees would be removed from the avenue’s median to create space for the stations.

350 “Apoyan Metrobús contra cambio climático (Supporting the Metrobús against climate change),” Reforma, December 6, 2003. Translation from Spanish by author.
CO2 emissions can then be sold to countries or actors willing to “buy” them through the World Bank’s Prototype Carbon Fund” (Rogers and Shipper 2005).

Therefore, this project must be understood in the context the interaction between players at the local and international level. The role of federal agencies, on the other hand, has been limited, with some involvement by INE in the analysis of benefits. While it was a locally-deployed project, the objectives that motivated the project were its mobility and local air quality benefits, as well as its role as an “experiment” in reducing carbon emissions in ways that could documented and sold in the form of carbon credits.

These international players played an important role in the planning and implementation of the corridor, and advising on the restructuring of the current scheme of public and private transit service provision along Insurgentes.351 There was also substantial collaboration with the World Bank and WRI with regards to the planning and design of the Metrobús, and the testing and selection of buses for the corridor. The 19.7-km corridor, with 34 stations and 2 terminals, was inaugurated on June 19, 2005, and is estimated to serve a demand of over 270,000 passengers daily. Below, we will discuss the ITS components of Metrobús, and its air quality impacts.

7.3.3 ITS Deployment

We will now describe the general deployment of ITS in the Mexico City Metropolitan Area. In the section that follows, we will then describe more specifically the linkages between ITS deployment and air quality management, in order to assess to what extent ITS has been deployed with an air quality objective.

7.3.3.1 Traffic

For Mexico City’s urban highways – Periférico, Circuito Interior, Viaducto – there is little real-time electronic data collection either through loop detectors or other types of roadside detection. There is no ramp metering, HOV lanes, or other types of managed lanes within the MCMA. As noted earlier, the highways leading out of the metropolitan area are frequently tolled. Electronic toll collection (called IAVE, sounding like llave or “key” in Spanish) lanes are available for many of the toll plazas. However, there are low levels of use by regular passenger travel. These highways have extremely high demand for weekend travel out of the city, particularly the highway to Cuernavaca, and thus present substantial back-ups on Friday evenings (leaving the city) and Sunday afternoons (entering the city).

Within the Federal District, there is more extensive traffic monitoring with CCTV, and real-time electronic data collection on traffic through loop detectors, both of which are controlled through the city’s Traffic Control Center. The city’s 172 CCTV cameras (pan-tilt-zoom) support traffic operations and responses to incidents, although there is often a lack of coordination in

351 One of the primary challenges was negotiating with the privately-operated colectivo services that would be replaced by the Metrobús, and incorporating colectivo owners and operators into a formal business operation were revenues would be collected centrally and distributed to operators.

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Images from the CCTVs are also fed to several television stations for traffic reporting. There are over 20 variable message signs (VMS) that—when providing accurate and real-time information on traffic conditions, incidents, and alternate routes—could serve to reroute traffic around incidents, construction, etc. However, the VMS are generally underutilized in terms of providing information to drivers, displaying messages with static information (such as reminders to use seatbelts), or providing unclear information and unhelpful instructions to drivers ("congestion ahead, use alternate routes").

In addition to recurrent congestion during peak periods, non-recurrent congestion from accidents and incidents is highly problematic. The physical geometry of Mexico City's limited access roads (i.e., lack of wide shoulders) often does not permit drivers to move disabled vehicles to the side of the road and out of the flow of traffic to avoid traffic buildups. In order to deal with non-recurrent congestion that can cause significant delays, and perhaps more importantly, high variability in trip times, some programs have been developed to provide roadway assistance for accidents and mechanical failures. Several years ago, Setravi instituted a program in the DF called "Roadway Help" (Apoyo Vial), which provides a "highway helper" service. "Radars" (Setravi personnel identified by their yellow uniforms) are available both for motorist assistance as well as for pedestrian assistance. The highway "radars" on yellow motorcycles, provide mechanic assistance (changing tires, providing gasoline, etc.) to motorists with disabled vehicles located on highways and other important avenues (such as Reforma and Insurgentes).

In the DF, the Secretary of Public Security (SSP) of the DF has primary responsibility for traffic management. Of the 50,000 intersections in the Federal District, over 3,076 are signalized. Of these signalized intersections, approximately 1,246 are interconnected, and about 1,810 are basic electronic signals with synchronized clocks (Secretaría de Transporte y Vialidad del Distrito Federal (Setravi) 2002, p 23). Of the 1,246 interconnected signals, approximately 300 signals are included in the adaptive control system, in theory, capable of changing signalization patterns to respond to real-time traffic conditions. The software used to control these signals is SCATS, which was developed in Australia. In discussions with officials from SSP in 2003, they suggested that there were plans to expand the system with 700 additional signals controlled using SCATS. However, private sector consultants for the SSP supporting the operations of the adaptive control system described a less optimistic picture of how well the system was functioning. According to them, the majority of the signals continue to operate in a semi-

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352 For example, according to engineers from the SSP, there is no common source for compiling information on traffic accidents, with many accidents not officially registered.

353 Peak hour travel in Mexico City is characterized by a morning peak (6:15 pm to 9:45 pm), afternoon peak during the Mexican hour of "comida" (14:00 pm to 15:45 PM), and evening peak (6:00 pm to 9:15 pm).


355 Personal communication, Engineer from the Department of Traffic Operations and Roadway Engineering from the Secretariat of Public Security (SSP), December 18, 2003.

356 Personal communication, Representative from INMER S.A. at Intertraffic Mexico, October 2004. According to the Secretariat of Public Security, INMER has worked with the government of the Federal District on traffic signal systems for 20 years. See www.ssp.df.gob.mx, last accessed July 5, 2006.
manual mode, with very few actually running in the fully adaptive mode. They suggest that in large part, this is to avoid taking the signal technicians and engineers “out of the loop” of signal control and timing upgrading, which could mean job losses for those employees.

7.3.3.2 Transit

Little ITS infrastructure currently exists for the road-based public transportation system in Mexico City, the majority of which is privately owned and operated as colectivo/microbus service. ITS technologies have only recently begun to gain notice as a viable option for improving the performance of public transit in the MCMA. Advanced systems have been deployed as part of Metrobús, the first bus rapid transit (BRT) on an exclusive busway in Mexico City. The primary ITS applications deployed are a contactless smart card, for pre-payment in the Metrobús stations and more recently, the use of Automated Vehicle Location (AVL) using GPS for both in-vehicle units and a bus operation control center. Traffic signal improvements were also made along the corridor, including additional signalization for pedestrian crossing with “count-down” displays. Pre-paid rechargeable smart cards are also being planned for extension to the subway system (Metro), and possibly throughout the rest of the government-operated bus service (RTP) and trolleybus and light rail service (STE).

The AVL systems and bus operations control center has only recently come online – six months behind schedule – to control headway between vehicles. To the author’s knowledge, there is no traffic signal priority as of yet, although this could be a possibility. There is also no real-time information on bus arrivals at stations, which is not especially necessary due to high frequency of service (every 3-4 minutes), nor are there in-vehicle stop announcements.

The deployment of Smart Cards could be an important step in moving toward a more intermodal public transit system, and allow for more diverse, differentiated fare policies, including transfers and discounts. It has also been essential for the financial reorganization of public and privately operated transit service on the Metrobús. The Metro and light rail both utilize single-use magnetic strip tickets (2 pesos) for entering into the stations. The government-operated RTP buses accept exact change only, also with a fixed rate of 2 pesos, while the private colectivo operators provide change, and charge variable fares depending upon the distance traveled. The routine of providing change, as well as frequently answering questions about the route and destination of the colectivo, also leads to significant dwell times.

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357 Iván Sosa. 2006. “Complican el pago de transporte local (Complicating local transit fare payment).” Reforma, June 11.
358 Iván Sosa. 2006. “Controlan Metrobús a través de satélites (Metrobús controlled via satellites).” Reforma, May 27.
359 There is some differentiation of fare policies by age, with “senior citizens” (60+) riding for free with identification. However, the only distance-based fare differentiation is found in the private sector colectivos, which generally charge in three increments of 50 centavos (approx. $0.05 US).
360 However, in some cases, the colectivo driver also has a type of assistant to deal with making change and other issues. Also, while the colectivos may have longer dwell times during passenger boardings, they make up time by not always coming to a full stop when letting passengers off of the vehicle.
Interviews with planners from Metro in 2003 had indicated that deployment of smart card fare payment would initially be tested and deployed in the subway system, then be extended to use on the BRT system. However, the Metrobús was the first system to deploy the smart card technology. There were delays in deploying the smart card system, to the extent that upon the opening of the Metrobús along Insurgentes, travel on the new system was free for several weeks, until the pre-paid smart card system was available.\textsuperscript{361} Even several months after the opening of the Metrobús Insurgentes, one of the principal problems continues to be the fare payment system, with problems leading to bottlenecks of people at the entrances to the stations.

Although the smart card is a supporting component of the BRT system, recent problems have highlighted its importance. According to the director of the Metrobús, “the functioning of the financial scheme is the most important part of the system, and it depends on the centralization of the revenues for Metrobús via the cards.”\textsuperscript{362} During the first eight months of operation of the Metrobús on Insurgentes, the main issue was the shortfall of buses to meet the demand without overcrowding. However, as more buses have been added to service, the focus has shifted to problems with the fare payment system. The tendency has been to blame the users. According to the director of Metrobús, most users, having previously used colectivos or buses, were used to paying in cash. Therefore, with the new system of rechargeable smart cards, they do not always add enough money to the card to pay for multiple trips, and therefore must “re-charge” the card each time. As a result, there is not a sufficient number of machines for dispensing and recharging fare cards at such high rate, meaning the queues at certain stations during peak hours can reach up to 15 minutes.\textsuperscript{363}

The AVL units provides real-time information both to drivers, showing their location and whether they are ahead or behind schedule, as well as to operators in the control center (Calderón Aguilera 2006).\textsuperscript{364} The vehicles are also equipped with radio communications so that the control center operators can give instructions to the drivers as to whether to accelerate or slow down to control headway between the buses. Like the smart card payment systems, the AVL units and bus operations control center were delayed in their deployment. However, now that they are in use, they appear to be providing substantial improvements to travel time, reducing travel time (north to south) from approximately 70 to 58 minutes, and increasing average speeds from 17 to 20 kph. There has also been a growth in ridership. The average weekday ridership was around 225,000 between the end of September and December 2005. Since January 2006, average weekday ridership has risen to approximately 260,000 (Calderón Aguilera 2006). Initial ridership projections were for 250,000 weekday riders on average. This ridership increase is likely due to a number of factors – improved frequency of service and comfort due to the addition of more buses, meaning less wait and less overcrowding in vehicles, as well as more reliable service due to improved headway control. It is interesting to note that a survey of the

\textsuperscript{361} Particularly during this period of “free” travel, there was substantial overcrowding of the buses. This was also due in part to an insufficiency of vehicles in the fleet, which was latter remedied through the addition of new vehicles.

\textsuperscript{362} Iván Sosa. 2006. “Saturan entradas del Metrobús (Metrobús’ entrances are saturated).” Reforma, April 25.

\textsuperscript{363} Iván Sosa. 2006. “Saturan entradas del Metrobús (Metrobús' entrances are saturated).” Reforma, April 25.

\textsuperscript{364} Also see Iván Sosa. 2006. “Controlan Metrobús a través de satélites (Metrobús controlled via satellites).” Reforma, May 27.
Metrobús riders, showed that 4.1% of users formerly used private automobiles, and 2% formerly used taxis (Calderón Aguilera 2006). Based on an average weekday ridership of 250,000 users, this would translate into roughly 15,000 trips shifted from private autos and taxis to public transportation – an important outcome.

Beyond Metrobús, other providers of public transportation have also adopted AVL-based systems for control of their fleets. For example, Metropolitan Transportation Group (Grupo Metropolitano de Transporte, or GMT), which operates a fleet of 50 vehicles, utilizes GPS which gives location information to drivers and dispatchers, and provides voice announcements to passengers on upcoming intersections and stops.365

Some additional applications for transit that have been considered include the combined use of “panic buttons” along with automatic vehicle location (AVL) to provide emergency police assistance to public transit vehicles, primarily the microbuses. This proposal emerged in 2003 after a number of violent assaults on passengers in microbuses, where the entire vehicle was essentially “abducted” and taken off the route, where passengers were robbed and often physically assaulted. Problems with finding vendors that would met the specifications established by the Secretariat of Public Security delayed the deployment of this system, and it is unclear how many units, if any, have actually been installed.

7.3.3.3 Information

Currently, there are several sources of information regarding traffic conditions on major routes in the MCMA, although nearly exclusively focused on the DF. While radio continues to be a key source of information on traffic conditions, an increasing number of Internet sites for traffic information are appearing, including sites developed by the Secretary of Transportation of the DF (Setravi) and Secretary of Public Security (SSP), and online newspapers (e.g. Roadway Alert from Universal newspaper) that integrates information from a number of sources including Setravi’s “Radares” as well as radio traffic helicopters.366 There is also a phone-based system as part of Setravi’s broader motorist support program, with traffic information and alternate route suggestions provided by live operators. It is unclear what sources of information the operators use, and the level of usage of this service. One of the limitations seems to be the lack of public information regarding the availability and use of these resources. Furthermore, it is unclear to what extent the information from various sources (radio helicopter, vehicle probes, CCTV, etc.) is integrated to give more comprehensive and detailed descriptions of road conditions.

7.3.4 ITS-Air Quality Links

Having described the history of air quality management and ITS deployment in Mexico City, we will now look at the links between ITS and air quality. We first look at ITS technologies that

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366 See www.eluniversal.com.mx/vialidad.html to see the format of traffic reporting, as well as the major sources of information regarding traffic incidents.
have been deployed or funded at least partially in support of air quality objectives, then turn to evaluations of the air quality impacts of ITS technologies.

7.3.4.1 Projects and Funding

With perhaps one or two exceptions, ITS technologies have not been deployed for both mobility and air quality improvements. ITS deployments have occurred in a much different institutional environment than in the US, and there have not been opportunities or incentives for linking ITS to air quality. First, in the absence of requirements to implement transportation control measures, as in the US – both demand management and supply management measures – the focus has remained almost entirely on improvements in new vehicle technologies and fuels, and turnover in older vehicles, particularly those with intensive use such as buses, microbuses, and taxis. Operational improvement to traffic and transit have not been at the forefront of air quality programs, and ITS-based operational improvements even less so. Second, the US federal CMAQ program provided much of the impetus for demonstrating and the air quality benefits of ITS technologies in the US. However, in Mexico, there is no such federal funding program, which could be used for experimentation with new technologies that reduce emissions and improve air quality at the same time that they are improving mobility. As a result, although there have been deployments of some ITS technologies intended to mitigate traffic congestion, there are no incentives for the deploying organizations to assess air quality impacts of traffic mitigation, or attempt to maximize the air quality benefits of those deployments.

More recently, however, ITS has been used in support of air quality objectives. The first example is the use of smart cards and AVL-based systems to support the Metrobús, a BRT project described earlier, which has a heavy focus on emission reductions. Another possible example is the motorist assistance program, Apoyo Vial, developed by Setravi. The link between Apoyo Vial and air quality is somewhat less strong. According to Setravi, this program was implemented, “with the purposes of improving traffic flow and avoiding excessive travel times and increases in already high levels of air pollution.”367 However, beyond this statement, there has been no evidence that this measure is an explicit part of air quality management in Mexico City.368 In contrast, Metrobús clearly has an air quality objective as well as a financial incentive, in the form of carbon credits, to document the air quality benefits of this project.

7.3.4.2 Evaluation

Generally, there has been low interest in the use of ITS to reduce emissions and fuel consumption. Rather, the focus has been on congestion reduction. One of the few examples of public sector interest in looking at the links between ITS and air quality, was an April 2002 working paper on ITS developed by an analyst from the Transportation Branch of the National Commission for Energy Savings (Dirección de Transporte de la CONAE). The document was generally an overview of ITS. However, it briefly discussed the potential environmental benefits of the following ITS applications:

368 For example, in the air quality management plan for the Mexico City metropolitan Area, Proaire 2002-2010, there is no similar measure included.
• *advanced traffic information*, by avoiding congested routes;
• *parking information*, by minimizing additional circulation of vehicles looking for parking;
• *real-time transit arrival/departure information*, by increasing the use of public transit;
• *real-time tracking of commercial vehicle operations*, by tracking speed and acceleration and enforcing proper driving techniques; and
• *ramp metering*, by reducing stop and go traffic on limited access highways.

Yet, there have not been evaluations of the reduction in emissions and fuel consumption from most current or planned technologies – signalization, VMS, electronic toll collection, CCTV, motorist assistance, or traveler information. In part, in the absence of a stronger federal role and active ITS community to lobby for ITS and highlight its benefits, little consideration has been given to these possible benefits. Even less consideration has been given to the possible negative impacts of ITS on air quality. According to a researcher at the Mexican Transportation Institute (IMT), the environmental and energy benefits of traffic management technologies is of “little concern” to those agencies deploying or interested in deploying ITS.369

Until more recently, evaluations of emissions reduction measures have focused on changes in vehicles and fuels, with little emphasis on to evaluating possible emissions reductions from changes in operational strategies – traffic flow improvements, improved transit operations, incident management strategies, etc. Again, Metrobús is the exception. A comprehensive analysis of emission changes from operational improvements at the corridor level was undertaken for the Metrobús. As noted earlier, the focus of this assessment has been on carbon dioxide emissions reductions, in order to make carbon credits available for purchase. The assessment took credit for emissions reductions from: (1) fleet vehicle replacements (articulated buses for regular buses and microbuses), (2) improved traffic flows, and (3) modal shift from private vehicles. It also considered emissions increases from: (1) impacts on traffic flows on cross streets, (2) vehicles detours due to elimination of many left turns on Insurgentes, (3) modal shift from the Metro, (4) additional vehicles using the route because of higher speeds, (5) construction impacts on traffic, and (6) emissions from construction itself.370 The strength of this analysis is in the comprehensiveness of the impacts considered, in terms of not only transit vehicle emissions but changes in emissions from changes in traffic flows. In this sense, it represents a rigorous analysis, albeit one that requires important assumptions on modal shifting, changes in travel times and speeds, and changes in route choice. It is hoped that many of these parameters will be measured in the field to confirm the actual emission reductions.

There are some areas in the Metrobús analysis where the balance between credits and debits are dubious. For example, credit was taken for “improvements in vehicle flows on other alternative routes in the area of influence of the corridor,” which indicates the diversion of a certain

369 Personal communication, Head of the New Technologies Unit, Mexican Transportation Institute (IMT), November 19, 2003.
percentage of vehicles from other routes in the city, to take advantage of the faster travel times on Insurgentes. As a result, traffic flows on those routes would be lighter, and emissions lower, as some drivers switched to Insurgentes. Yet, on the other hand, there would now be additional vehicles using Insurgentes because of its higher speeds. This would lead to a higher volume of vehicles, and perhaps a return to slower speeds on Insurgentes. While this dynamic was identified in the analysis, its effect on emissions on Insurgentes considered to be null, despite the fact that credit was taken for traffic relief on alternate routes. It is unclear whether these are mistaken assumptions, poor accounting practices, or attempts to show greater emissions benefits.

Because the smart card fare payment system and AVL are both supporting functions, it is difficult to assess the relative impact of these ITS technologies on the overall system. Yet, recent problems with the fare payment system have highlighted the importance of electronic fare collection to the functionality of the system and service levels. In addition, there are some indications that the service improvements from the AVL-based systems and new bus operations center for Metrobús may be supporting ridership increases by enabling a higher frequency and more reliable service.

There are some recent indications that in Mexico City, ITS is being seen as a technology that can support both mobility and air quality goals. These synergies have mostly been realized through the deployment of a more ITS-intensive public transit service, the Metrobús. This new service innovation is viewed as contributing to improvements in local air quality, as well as reductions in greenhouse gas emissions. Having reviewed the history of air quality management and ITS deployment in Mexico City, and explored some of the links between ITS and air quality, we now present the analysis of Mexico City using the IIDAPT framework.
7.4 ASSESSING THE POSSIBILITIES FOR IIDAPT

In a manner similar to the US case study cities, we will review the seven conditions for Integrated Innovation, Deployment and Adaptation of Public Technologies (IIDAPT), the levels of IIDAPT that they would predict, and compare that with actual IIDAPT outcomes. More importantly, in the case of Mexico City, we will use this analysis to develop recommendations for the use of ITS in ways that promote both mobility and air quality objectives. The purpose of this section is therefore not only to further test the theory against a new case, but also to assess to what extent the theory can be used to develop useful technology and policy recommendations. We consider the latter to be the key contribution of this chapter.

7.4.1 Seven Conditions for IIDAPT and Predicted IIDAPT Levels in Mexico City

To reiterate, in Chapter 4, we reviewed theories regarding innovation, cooperation, assessment and adaptation in public sector agencies, specifically regarding the deployment of technologies in the public sector. We identified seven conditions, and used those to construct a theoretical framework to predict levels of what we call Integrated Innovation, Deployment and Adaptation of Public Technologies (IIDAPT). Figure 7-8 reviews those seven conditions and illustrates their relationship to IIDAPT outcomes.

Figure 7-8 Relationship between seven conditions, IIDAPT outcomes, and local context

In earlier chapters, we also noted that local context was an important factor in describing IIDAPT outcomes in more depth. Local context can support the explanatory power of our theoretical framework. Yet, the predictive function of the IIDAPT framework depends upon the seven conditions highlighted in the diagram above. The reader is referred to Chapters 4 for the
theoretical basis for these conditions, and Chapter 6 for the discussion of how we measured these seven conditions for the US case study cities. In order to test our framework, we compared predicted IIDAPT outcomes to actual IIDAPT outcomes. Actual outcomes were described, and compared using three quantitative measures.

In testing the IIDAPT framework, we found that three conditions were the most important in predicting and explaining IIDAPT outcomes: (1) problem severity, (2) mutual benefits, and (3) dedicated resources. We will now apply this theoretical framework to the case of the Mexico City Metropolitan Area, to assess to what extent it predicts and explains IIDAPT outcomes, and whether these three most important conditions for the US case cities, are also the strongest in predicting and explaining IIDAPT outcomes in Mexico City.

Problem severity in Mexico City is high from the standpoint of the physical problem of air quality and traffic congestion. Clearly, with more than 60% of the days exceeding the established national norms for healthy air quality, there is a significant air quality problem. However, for consistency with our approach to the US cases, we suggest that the nature of the problem, as perceived by the public sector organizations, may be different. In the US, problem severity was defined as the non-attainment designation given by the federal government. Thus, for innovation, more important than the severity of the physical problem (in terms of pollutant concentrations), were the requirements and responsibilities that came with the regulatory designations ranging from marginal to extreme non-attainment. Increasingly severe non-attainment designations posed progressively stricter requirements to show that transportation plans conformed with the objectives of air quality plans, and requirements to implement all reasonably available transportation control measures (TCMs), as well as to report on the progress and “timely implementation” of those TCMs. The “stick” wielded in the case of the US, was the ability of the federal government to delay federal funding for transportation projects. However, in Mexico City, in the absence of these federal requirements and the link to federal transportation funding, the problem definition is driven from the bottom up, and may wax and wane with shifts in public opinion and in the preferences and interests of elected officials. This can therefore undermine the continuity of actions taken in the transportation sector to improve air quality, as public opinion focuses on other issues (even other environmental issues such as water), or as changes in administrations bring new political priorities to the scene.

Congestion is also severe. There are no equivalent indicators such as the travel time index (which measures the ratio of peak hour travel times to free flow travel times) or other aggregate measures of delay and/or reliability in travel times for the MCMA. However, from the levels of service described above, indications are that congestion is a pernicious problem. Moreover, in addition to looking at the problem of traffic congestion, which affects the majority of the traveling population in the US case study cities, we must include the deterioration of public transportation, in our description of problem severity for the MCMA. Coupled with congestion, which has progressed from bad to worse, is the growing motorization and loss of mode share by higher capacity public transportation, as effectively illustrated in Figure 7-3 above.

We are more interested, however, in the “problem severity” of air quality in terms of the demand/pressure for action and innovation by local transportation and air quality agencies, as
discussed in Chapter 6. Following our discussion in Section 7.3.2.3, we note that in the absence of contingencies, the national air quality standards have a tenuous regulatory link to transportation planning and operations. Although it may seem counterintuitive given the seriousness of the physical problem, we rank problem severity as medium, because of the more lax regulatory requirements.

Looking at our second condition – internal resources to both innovate with and assess new technologies – we find that they were low. Low levels of IIDAPT for ITS and air quality were largely expected, primarily because of the low levels of ITS deployment that had taken place. This means that there is little deployment and operational experience with ITS, and agencies do not have a large staff capable of deploying and managing ITS. In part, the educational systems have not yet begun to produce engineers with the training to deploy ITS. Universities, such as UNAM, do provide graduate programs in transportation engineering. In addition, the National Polytechnic Institute (IPN), is one of the only Mexican universities with an undergraduate program in transportation engineering. Yet, even in these programs, the students have very little exposure to the concepts and technologies of ITS. Therefore, the training of personnel with an understanding of ITS technologies and broader system issues has not been sufficient to provide an adequate pool of transportation professionals in this field.

There is also an absence of internal resources in terms of measuring and modeling the impact of transportation projects, operational or otherwise. In the US, the requirement to demonstrate the conformity of transportation plans with air quality plans, staying within mobile source budgets, was a struggle for non-attainment areas to develop the necessary institutional capacity during the early years of conformity, and will likely be a struggle for new non-attainment areas under the 8-hour ozone standard (Makler and Howitt 2003). However, there have been no similar federal pressures through legislation to "ramp up" transportation and air quality planning and management capabilities in Mexico. For example, even in Setravi, where the majority of the analytic capacity for transportation planning in the MCMA resides, the models used are generally poor in terms of data and complete modeling capabilities.

"Although it is known that traffic congestion causes pollution and mobility problems for the population, exactly how it does so is poorly understood. Government agencies in the MCMA have limited urban modeling capacity due to a lack of information and resources to collect and process information (as indicated by the fact that the most recent travel survey was conducted in 1994). To our knowledge, no complete urban transportation model (four-stage or akin model) exists for recent years. This means that behavioral aspects of urban travel and their consequences on air quality and mobility have not been analyzed." (Gamas, Anderson et al. 2006).

371 The author presented two guest lectures on ITS at IPN, and found varying levels of interest, from enthusiasm to deep skepticism regarding the appropriateness and possible benefits of using ITS in the Mexican context. Looking at the program content and coursework, there appears to be little to no exposure to ITS for the students.
Although analyzing the air quality impacts of traffic flow improvements, or changes to transit operations and ridership increases, incident management programs, do not necessarily need a highly sophisticated model,\(^{372}\) one does need reliable data.

Above, we mentioned the “stick” of withholding federal funding. On the other hand, there is also the “carrot,” which in the case of the US, is the availability of CMAQ funding to pursue innovative projects for mobile source emissions reductions. While in the US, dedicated resources for experimentation came in the form of the CMAQ federal program funding category, targeted to both congestion mitigation and air quality improvements, there is no equivalent federal-level funding program in Mexico. Therefore, dedicated resources are considered low. They would be considered as none, if not for the potential for financing projects through carbon credits, as occurred with the Metrobús.

The potential to sell carbon credits on the international market is somewhat analogous to having a dedicated funding source for innovative transportation projects documenting air quality benefits. If projects could be shown to generate emissions reductions, those emissions reductions could be sold, and thus generate income that could be reinvested into those projects. However, while the Metrobús experience showed that this could be an effective mechanism for orienting a project toward maximizing its emissions benefits (albeit of greenhouse gas emissions, and not emissions of local air pollutants), it was basically a one-time effort meant to be the “seed” for a more expansive BRT system. In addition, ITS was simply a component in a much larger project. It is doubtful that ITS projects on their own would quality for carbon credits, particularly traffic flow improvements that have a higher potential for induced demand. However, the Metrobús experience is useful as an indication that “dedicated resources” can be an effective incentive to undertake IIDAPT in Mexico.

In terms of the cost of ITS, for example, whether it is perceived as an affordable measure, or its relative cost effectiveness compared to conventional infrastructure improvements, we consider it to be medium. The low level of ITS deployments in Mexico makes it harder to establish a rough (order of magnitude) comparison between a “typical” ITS project and a “typical” capital infrastructure project. Although ITS costs are still likely to be substantially lower compared to larger capital infrastructure projects, ITS projects may be relatively more expensive in Mexico. The primary reason for this is the cost for the communications components. For example, leased lines would have to go through Telmex (Telefonos de Mexico). Generally, telecommunications services are more expensive in Mexico than in the US, in part because of market dominance held by Telmex for most telecommunications services (local and long-distance, internet service, wireless).\(^{373}\) Also, because transportation agencies had not begun to deploy their own communications links until more recently, they have been dependent upon Telmex for maintenance. Interviews with engineers from the Secretariat of Public Security (SSP) indicated that part of the problem with their variable message signs was due to failures in the telephone

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\(^{372}\) Indeed, even in cities such as Houston and Los Angeles, as described in Chapter 6, estimates for ITS air quality benefits are often made with simple equations that require no simulation or complex calculations.

\(^{373}\) Telmex was formerly owned by the federal government, until it was privatized during the administration of ex-president Carlos Salinas.
lines leased from Telmex, and that they themselves could not correct these failures in critical communication links. 374

The condition of mutual benefits reflect to what extent ITS can be used to support the policy goals of the various transportation agencies and air quality agencies. Therefore, mutual benefits would be high, in principle. Congestion and air quality are both critical problems in the MCMA, and public transportation quality has declined substantially. Given the currently low levels of deployment of ITS, there should be ample opportunities for “optimizing” the system – reducing congestion and increasing traffic speeds to a point where lower emissions occur, reducing delays and improving reliability, making public transit operational improvements and improving public transit’s image, and so on. Yet, mutual benefits must be defined in terms of the underlying interests and agendas of agencies and decisionmakers. The specific interests and agendas of the agencies in the Mexico City case will be discussed further in Section 7.4.3, after comparing predicted and actual IIDAPT outcomes.

The number of agencies is high, making coordination difficult. Leaving aside for a moment the question of metropolitan-level coordination, the agencies that would potentially be involved in the Federal District alone for traffic flow improvements, transit improvements, and demand management measures through ITS would include: the Secretariats of Transportation and Roadways, Public Works and Services, Public Security, Environment, and three different government-operated transit services – Metro, light rail and trolleybuses, and regular buses. Extension of ITS-based transit improvements to the private sector operators would involve dealing with a highly decentralized ownership and management structure, albeit organized through Route Associations. The recent implementation of the Metrobús with both public and private participation, however, points the possibility of this integration of operations, if there is a more limited number of Route Associations with which to negotiate.

As noted earlier, agency mandates and responsibilities, as defined in the legislation, are highly fragmented. However, the DF is also characterized by “a highly centralized, city-wide and mayor-headed local authority” (Nava Escudero 2001, p 112). As a result, fragmentation of administrative functions can be overcome by strong mayoral intervention. However, the outcome can also go beyond simple cooperation. Given the overlap in agency responsibilities and sometime vague legislative mandates, one agency can actually be allowed to appropriate many of the responsibilities that, in theory, would belong to other agencies. Therefore, we would expect some success of cooperation within the DF. If we were to extend our analysis to the entire MCMA, including the State of Mexico, our possibilities for cooperation would drop to low.

Finally, the levels of new information regarding the air quality impacts of ITS deployments, are low or none. There has been little interest by researchers in academia and the public sector to date to assess the air quality benefits of ITS in Mexico. Given the low levels of ITS deployment, there is admittedly a small base of applications with which to analyze these issues. Also, most of the generation of information on transportation and air quality has focused (and with good

374 Personal communication, Engineer from the Department of Traffic Operations and Roadway Engineering from the Secretariat of Public Security (SSP), December 18, 2003.
reason) on fuel and vehicle improvements, where most reductions have come from, and where there continue to be potential for additional reductions.

Taking these factors together, we would anticipate medium overall levels of IIDAPT as seen in Table 7-7. Strong mutual benefits would point to the possibility of cooperation and innovation in the use of ITS for air quality, at least within the Federal District. On the other hand, problem severity, in terms of the pressure on agencies to identify transportation-related measures for air quality improvements, is only medium, and dedicated resources and internal resources are low. Therefore, we anticipate only medium levels of innovation and cooperation. Because there has been little new information generated regarding the air quality impacts of ITS, and internal resources for undertaking this type of analysis are weak, we anticipate low levels of assessment and adaptation of ITS technologies to improve air quality outcomes.

7.4.2 Actual IIDAPT Levels in Mexico City

Few of Mexico City’s relatively “older” ITS applications, such as variable message signs, advanced traffic signal control strategies, have been considered as measures that could also improve air quality by either the agencies deploying those technologies (i.e. Secretariat of Public Security of the DF), or the environmental agencies (i.e. Secretariat of the Environment of the DF). Electronic toll collection on intercity highways has been around for much longer, but market penetration has not been high. The air quality benefits of an expanded ETC have not been seriously assessed. However, emerging ITS deployments for transit, such as smart cards and AVL-based operational improvements, have begun to take into consideration the potential benefits for air quality.

Drawing from Section 7.3.4 above, only three examples of possible IIDAPT were identified: (1) the use of smart cards for the Metrobús, (2) the use of AVL for the Metrobús, and (3) the motorist assistance program (Apoyo Vial).

However, the motorist assistance program is not very innovative in terms of technology, nor does it involve cooperation between multiple agencies. In addition, the link between the Apoyo Vial program and air quality management plans is weak, as discussed earlier. We therefore find only two cases of IIDAPT in the use of ITS as a supporting measure for transportation-based air quality improvements in Mexico City – the implementation of smart card fare payment technology and AVL-based operational improvements for the BRT corridors. These are summarized in Table 7-6 (while the scoring and calculation of IIDAPT outcomes is included in Appendix E).

Table 7-6 IIDAPT level and range in Mexico City

<table>
<thead>
<tr>
<th>ITS application areas</th>
<th>Representative technology</th>
<th>IIDAPT scale</th>
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<tbody>
<tr>
<td>Arterial traffic flow improvements</td>
<td>—</td>
<td>N/A</td>
</tr>
<tr>
<td>Freeway management strategies</td>
<td>Apoyo Vial motorist assistance</td>
<td>N/A</td>
</tr>
<tr>
<td>Freeway traveler information</td>
<td>—</td>
<td>N/A</td>
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<tr>
<td>Transit information</td>
<td>—</td>
<td>N/A</td>
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<tr>
<td>Multi-modal information</td>
<td>—</td>
<td>N/A</td>
</tr>
<tr>
<td>Transit operational improvements</td>
<td>AVL for Metrobús</td>
<td>4.5</td>
</tr>
<tr>
<td>Transit fare payment systems</td>
<td>Smart Cards for Metrobús</td>
<td>4.5</td>
</tr>
<tr>
<td>Rideshare support</td>
<td>—</td>
<td>N/A</td>
</tr>
<tr>
<td>Demand management/pricing</td>
<td>—</td>
<td>N/A</td>
</tr>
<tr>
<td>Other applications</td>
<td>—</td>
<td>N/A</td>
</tr>
<tr>
<td>Average level (0-6)</td>
<td></td>
<td>4.5</td>
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<tr>
<td>Range of IIDAPT (0-10)</td>
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<td>2</td>
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</table>

The “average level” of IIDAPT is quite high, with 4.5 out of 6, due to the very close involvement of the air quality agency in the DF in the design and the deployment of the project, and the use of innovative technologies such as contactless smart cards for fare payment and GPS-based AVL systems for fleet control. On the other hand, the “range” of IIDAPT examples is very low, and both cases of IIDAPT are, in fact, part of the same project. For the US case studies, we also used a measure of “intensity” as our third quantitative measure. However, the intensity of ITS as a measure for air quality improvement, according to Mexico City’s most recent air quality plan – Proaire 2002-2010 – could not be determined due to a lack of specificity of project descriptions. For the US case studies, the IIDAPT summary measure was the product of average level, range and intensity (AL*R*I). In the absence of an adequate measure of intensity, we take a high average level, and low intensity, to give an overall IIDAPT measure of medium (as shown in Table 7-7).

Although traffic signal improvements have been made and further improvements are planned, the possible air quality benefits of those improvements have not been considered in any depth by either transportation or air quality agencies. To a large extent, this is because of the relative marginalization of the Secretariat of Public Security as a serious player in improving congestion in the city. An example of this is the plan “100 Actions to Improve Traffic Flow,” in which, as described earlier, the Secretariat of Public Works and Services and Setravi developed a plan for intersection improvements, without mentioning either the Secretariat of Public Security or congestion mitigation from signal improvement strategies. Setravi, for its part, has extended

376 Although considered as a possible example of IIDAPT, there was no concrete evidence that this program was considered as an emission reduction measure or as part of an air quality management plan.

377 Interviews with the SSP indicated that some simulations were planned to assess the fuel consumption impacts of the signal control system. Personal communication, SSP, December 18, 2003. However, the author was not able to ascertain whether those studies had actually been carried out and what the results of those studies were.
some of its competencies to traffic flow operations through its motorist assistance program (*Apoyo Vial*) and traffic information service.378

### 7.4.3 Comparison and Discussion

Therefore, in our final “testing” of the IIDAPT framework, we find that actual outcomes (based upon quantitative measures of average level and range of IIDAPT) do coincide with outcomes predicted by the seven conditions for the case of Mexico City.

<table>
<thead>
<tr>
<th>Theoretical Outcomes</th>
<th>“Predicted” outcomes based on seven conditions</th>
<th>Actual Outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Seven conditions from theory</strong></td>
<td><strong>Summary:</strong> MEDIUM</td>
<td><strong>Summary:</strong> MEDIUM</td>
</tr>
<tr>
<td>1. Problem severity – med</td>
<td>• Innovation – med</td>
<td>High average level, low range, intensity not available.</td>
</tr>
<tr>
<td>2. Internal resources – low</td>
<td>• Cooperation – med</td>
<td>Description:</td>
</tr>
<tr>
<td>3. Dedicated resources – low</td>
<td>• Assessment – low</td>
<td>No IIDAPT for traffic management on arterials or freeways.</td>
</tr>
<tr>
<td>4. Cost – med</td>
<td>• Adaptation – low</td>
<td>Two innovative examples of IIDAPT for transit through the <em>Metrobús</em> on <em>Insurgentes</em> Avenue.</td>
</tr>
<tr>
<td>5. Mutual benefits – high</td>
<td></td>
<td>Quantitative measures:</td>
</tr>
<tr>
<td>6. Number of agencies – high</td>
<td></td>
<td>• <em>Average level:</em> 4.5/6</td>
</tr>
<tr>
<td>7. New information – low</td>
<td></td>
<td>• <em>Range:</em> 2/10</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• <em>Intensity:</em> Some measures in <em>Proaire</em> 2002-2010 could utilize ITS, but are not specified in sufficient detail to assess.</td>
</tr>
</tbody>
</table>

As was the case with the US cities, IIDAPT levels can be predicted based upon the seven conditions. However, also similar to the US, the broader context of both air quality management and transportation planning and investment is important. While we can predict IIDAPT levels, it is necessary to look at this broader context to explain outcomes in a more meaningful way. Therefore, we pose some additional questions. Why were technologies for the *Metrobús* the only case of explicitly using ITS technologies to improve both transportation and air quality outcomes in the DF? Also, given that the high levels of congestion are recognized as aggravating Mexico City’s air quality problems, why has ITS not been promoted as a way to mitigation congestion and improve air quality?

As noted earlier, the Secretary of the Environment has been the primary public official for representing the Second Stories, the *Metrobús*, and the bikeways. Bringing this back to our

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378 See [www.setravi.df.gob.mx/radar_vial/index.html](http://www.setravi.df.gob.mx/radar_vial/index.html) for web-based traffic information. This site basically lists problem areas as they identified and reported – there is no continuous monitoring of traffic speeds and delays.
theory, this represents an unusual form of overcoming fragmentation between transportation and air quality management strategies, in which the Secretariat of the Environment has assumed substantial decisionmaking and planning authority for major transportation projects.\textsuperscript{379} One might assume that placing an environmental agency at the head of major transportation investment decisions would improve the environmental outcomes of those decisions. However, this does not \textit{necessarily} seem to be the case. In fact, the more cynical interpretation would be that the Secretariat of the Environment was placed at the head of these major projects, above all, the controversial Second Stories project, in an attempt by the administration to deflect criticisms of the environmental and air quality impacts of the project.

In the DF, during the administration of Mayor López Obrador, the Secretariat of the Environment appeared to take on many of the transportation-related activities that normally would have been the responsibility of the Secretariat of Public Works and Services and \textit{Setravi}. The \textit{Metrobús} project was a more natural extension of the Secretariat of the Environment’s role. Indeed, the SMA was critical in assessing and documenting the carbon dioxide emissions reductions in order to enable their sale as carbon credits through the Clean Development Mechanism program. However, as mentioned above, the intentions behind placing the Secretariat of the Environment in charge of the double-decking of two urban highways, are probably not as noble. This institutional reshuffling, with the Secretariat of the Environment taking the lead on the most important infrastructure projects of the 2000-2006 administration, would sideline \textit{Setravi}, the Secretariat of Public Works, and the Secretariat of Public Security to more secondary positions for decisions regarding transportation investment.

This unique modification to the interagency relationships in Mexico City has had important ramifications, both positive and negative, for the potential for using ITS in support of air quality. With respect to the two major transportation investments made during this administration, it was essentially positive for those technologies ITS used for transit, but negative in terms of the potential to use ITS for traffic management. In the Federal District, the preference was for improving bus services, and beginning to rein in the privately-operated \textit{colectivos}, rather than investing substantial more funds in the Metro subway system. Indeed, planners from the Metro have repeatedly lamented that the Metro’s “Master Plan” is several years behind schedule.\textsuperscript{380}

The potential for partially financing BRT through the sale of carbon credits, and the support of international players such as the World Bank and WRI, would reinforce the efforts to develop an “environmentally-friendly” transportation system. This also followed the success of the city of Bogotá, Colombia, where Mayor Enrique Peñalosa built an extensive BRT system called \textit{Transmilenio}, which has been highly praised by transportation professionals worldwide, and mimicked in other cities across Latin America, Asia, the US and elsewhere. This focus on BRT, which is a more ITS-intensive service, would also create a more favorable environment for fostering the use of ITS in public transit. As a result, smart cards and AVL were incorporated

\textsuperscript{379} Politicians from the opposing parties, particularly within the Federal District’s Legislative Assembly, often criticized what they saw as an overstepping of the functions of the Secretariat of the Environment, referring to the post as the “Super-secretary.” See “Cuestionan a la ‘supersecretaria’” (Questioning the ‘Super-secretary’)” \textit{Reforma}, October 9, 2003.

\textsuperscript{380} In fact, there were no new kilometers of Metro lines built during the 2000-2006 administration.
into Mexico City’s first BRT line. This reflects a similar dynamic which has occurred in other Latin American cities, which have increasingly deployed bus rapid transit systems, rather than construct new or expand existing subway systems or metros. According to Menckhoff, “the development of BRT technology has changed the equation and is affecting the decisions on new metro start-ups, as illustrated by the bases of Bogotá and Curitiba” (Menckhoff 2005, p 19). During the implementation of the Metrobús, there was no extension of the Metro or light rail. As a sidenote, this sidelining of the Metro might not have been possible in earlier years, when the Metro and the construction firm, ICA, had major political clout in the DF. 381

At the same time, massive funds were being used to construct Second Stories over the highways Periférico and Viaducto – a major capital infrastructure expansion. This project was billed as being the only possible solution to traffic congestion for this important corridor. Indeed, there was no consideration of alternatives, in a way that would be comparable to a major investment study in the US. In fact, the time from the first public announcement of the project by the Mayor, to the beginning of construction of the supporting flyovers and interchanges (Distribuidor San Antonio) was only seven months (see Table 7-8). Indeed, work for this flyover was already underway when, amid criticism of the project, a public plebiscite was held to say “yes” or “no” to the construction of Segundos Pisos. 382 Clearly, in this context, there was no motivation to simultaneously explore the congestion mitigation possibilities of ITS, as an alternative or even complement to the infrastructure expansion, in the face of substantial pressures by the Mayor to initiate and complete construction. The time from the submission of the Environmental Impact Statement, to the public consultation on the EIA, to the final approval of the EIA, was one month (see Table 7-8). 383

<table>
<thead>
<tr>
<th>Table 7-8 Timeline for major transportation actions in the Federal District</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>December 5, 2001</strong></td>
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<tr>
<td><strong>January 11, 2002</strong></td>
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<tr>
<td><strong>February 14, 2002</strong></td>
</tr>
<tr>
<td>February 18 - March 8, 2002</td>
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381 During the 1970s and 1980s, the Metro was a powerful public agency, heavily subsidized by the federal government (and by extension, by the rest of the country) through special appropriations Ward, P. M. (1998). Mexico City: The production and reproduction of an urban environment. Boston, MA, G.K. Hall & Co. It was also closely aligned with the largest construction firm in Mexico, ICA (Ingenieros Civiles y Asociados), which “[pressed] the government to raise investment in transportation systems, most notably the Metro” Ward, P. M. (1998). Mexico City: The production and reproduction of an urban environment. Boston, MA, G.K. Hall & Co. The decentralization of administration and financial resources of the Federal District, described earlier in Section 7.2.1, changed this dynamic and undercut the role of the Metro in transportation planning decisions in the DF in more recent years.

382 CESPEDES and other groups criticized the fact that the plebiscite was set up as a simple yes or no decision on a single project, without consideration of alternatives such as public transportation, and without mention of the cost involved in the double-decking of these roadways.

383 This very quick review and approval process is worrisome given criticisms of weaknesses in both the content of EIA, and problems in the review and approval process for EIA. See Section 7.2.3.3 above.
March 1, 2002  | Public consultation on the Environmental Impact Statement for the *Segundos Pisos*.

March 15, 2002 | The Environmental Impact Statement for the *Segundos Pisos* is approved by the Secretariat of the Environment of the Federal District.

July 2002   | Work begins on the flyover *San Antonio*, connecting to *Periférico*.

September 22, 2002 | Public plebiscite on the *Segundos Pisos*.

November 5, 2002 | Integrated Program for Transportation and Roadways (*PITV*) published in the *Gaceta Oficial* of the Federal District. It includes the *Metrobús* and *Segundos Pisos*.

September 17, 2003 | Construction begins on the first phase of the *Segundo Piso* over *Periférico* (from San Jerónimo to Las Flores).

February 15, 2005 | Construction begins on the second phase of the *Segundo Piso* over *Periférico* (from Las Flores to San Antonio).

June 19, 2005 | *Metrobús* begins operations (with no fare).

July 10, 2005 | *Metrobús* begins charging fare with paper tickets (3.5 pesos ≈ 30 cents)

August 2005 | Smart card systems for *Metrobús* come online.

Spring 2006 | AVL-system and the supporting *Metrobús* operations control center begin operation.

Source: [www.fimevic.df.gob.mx](http://www.fimevic.df.gob.mx), Reforma newspaper, (CESPEDES 2002), and April 2006 presentation by the General Director of Metrobús (Calderón Aguilera 2006).

As a result of the institutional modifications and spending preferences during the administration of López Obrador, little consideration was given to ITS as a tool for both traffic management and air quality improvements. First, in the light of the Second Stories project, there were no incentives to investigate the congestion mitigation and air quality improvements that could possibly be generated by ITS-based operational improvements. As discussed above, this project was promoted as a “take it or leave it” solution to congestion on these particular roadways – stifling discussion on possible alternatives, operational or otherwise. Second, as the Secretariat of the Environment took on many of the responsibilities of the major transportation agencies – *Setravi* and the Secretariat of Public Works and Services – the other agencies with responsibilities for traffic management, such as the Secretariat of Public Security, which was already a secondary actor to begin with for transportation issues, was pushed further out from the locus of decisionmaking.

In summary, the spending preferences of the administration of DF Mayor Andrés Manuel López Obrador were for major highway expansion projects on the roadway side, and for BRT on the public transportation side. There was no incorporation of ITS into the highway projects, specifically, for the double decking of the *Periférico*. On the other hand, there was greater use of ITS in public transportation, given that BRT generally lends itself to more technology-intensive operations. We saw that the BRT was motivated in part by its potential environmental benefits,

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385 See [www.fimevic.df.gob.mx](http://www.fimevic.df.gob.mx) for a description of the various roadway projects (in Spanish) including the Second Stories and flyovers/interchanges, bridges (primarily in the eastern part of the city), and a series of overpasses and underpasses.
specifically, the generation of carbon credits that could be, and were in fact, sold. Yet, we could go further, and suggest that even BRT supported the administration’s preferences for large scale investment in highway infrastructure, precisely because of BRT’s lower cost. It would have been politically unacceptable for the Mayor to invest such a large quantity of public funds into the double decked project, without showing important progress in expanding public transportation as well. However, it would have been financially infeasible to invest both in the second-story highway expansion projects, simultaneously with an expansion of Metro lines — another highly capital intensive project.

While the context of Mexico City differs substantially from that of the US case study cities, the dynamics of these cases are similar, in that ITS deployments for air quality often reflect preferences for large-scale investments. For example, in Boston, the preference of the MBTA is to avoid several transit projects that involve extending or restoring rail-based services, in favor of ITS-based solutions for bus rapid transit type service, that could be considered an adequate substitute of Boston’s transit commitments. In Houston, on the other hand, Metro has been attempting to push a transit expansion program based on light rail. Therefore, they have highlighted the air quality benefits of light rail, while making little reference to the air quality benefits of improvements to bus services through ITS. Houston was also continuing to support its case for continued investments in TranStar, the hub of ITS deployment in the region. Therefore, the air quality benefits of TranStar have been repeatedly stressed by the agencies involved in TranStar. Los Angeles, has shifted transportation priorities radically, away from infrastructure expansion, to demand management and transit expansion. Therefore, while there is a focus on the air quality benefits of applying ITS to transit, and to a more limited extent, to demand management (under their information-based transportation strategies category of TCMs), there seems to be a reluctance to highlight the potential air quality benefits of better managing traffic flow on local streets and highways. These issues are discussed in depth in Chapter 6. However, it is important to highlight the similarities between these very different cities.

386 In response to criticism of the share of funding spent on highway infrastructure compared to public transportation, officials from the DF often countered by showing the predominance of the Metro in annual expenditures of the DF budget. However, the vast majority of these expenditures are operations and maintenance expenditures.
7.5 TECHNOLOGY AND POLICY RECOMMENDATIONS FOR THE MCMA

There have been only a few comprehensive studies looking at the role of ITS in developing countries. A team from the World Bank developed a series of working papers and technical notes regarding the application of ITS, including issues such as ITS architectures and standards, in developing countries in East Asia, Latin America and Eastern Europe (Toshiyuki, Weiland et al. 2005).387 There also has been some work on the role of ITS in sustainable transport for developing country cities as part of the Sustainable Urban Transportation Project (Sayeg and Charles 2005).388 Our analysis will differ in several ways. First, we will make recommendations only for the case of the Mexico City Metropolitan Area, based upon the description and analysis presented above. Second, we will focus specifically on how ITS can be deployed in ways that support mobility and air quality. Therefore, this does not explicitly address other important goals of ITS deployments such as safety. Third, while we will look at technology recommendations, the primary focus is to use the framework for IIDAPT to identify the institutional and organizational changes needed to better incorporate air quality concerns into ITS deployment. While specific to the case of the MCMA, many of the recommendations — both technology and policy recommendations — may be useful for other cities facing similar issues and challenges.

This first part of this section (7.5.1) will describe the technology recommendations for the MCMA. This will be based on our discussion of ITS deployment and specific transportation and air quality challenges in the MCMA. It will also draw heavily on Chapters 2 and 3, in which we reviewed the state of knowledge on air quality impacts of different ITS applications, and on Chapter 6, where we identify some “best practices” in the use of ITS for air quality in our five US case study cities. In the second part of this section (7.5.2), we will then look at the policy and institutional options for the MCMA, using our theoretical framework for IIDAPT. This will also complement Section 7.5.1, to describe how organizational and institutional changes can be made to better align ITS deployment in favor of air quality goals.

7.5.1 ITS Options for Air Quality Improvements

Building upon our discussion of existing ITS deployments in Mexico City, we will identify technologies with a high potential for emission reductions. The US cases and the analysis presented in Chapter 6 pointed us to some of the most frequently used ITS technologies for air quality improvements. We will assess the applicability of some of these “best of” technologies for Mexico City, keeping in mind the important difference in travel patterns in Mexico City, above all the predominance of transit, particularly private/informal transit, in the mode share. For this reason, we start with the ITS technologies to improve air quality by maintaining or increasing transit’s share of the modal split.

388 Also see www.sutp.org or www.gtz.de/transport for more information on the Sourcebook on Sustainable Urban Transportation. Last accessed May 8, 2006.
7.5.1.1 Transit Improvements

With public transit still serving the majority of trips in the MCMA, we would recommend continuing to focus on the application of ITS to support broader improvements in public transit operations and enhance the image of public transit to travelers who may have more recently abandoned public transit in favor of the private auto. Having now been deployed for the Metrobús along Insurgentes, a next step would be to expand the use of the smart card to other modes. This could enable a better fare integration that would assist users making trips on multiple modes – i.e. Metro, light rail, trolley and RTP buses. As operational experience is gained with the BRT-type systems, the potential for other supporting ITS applications – signal priority, automated enforcement, etc. – should be also considered to assess their ability to further improve transit services and improve the emission impact of those services.

Dedicated and barrier-separated bus lanes are an effective means for ensuring shorter, more reliable travel times and enabling higher passenger flows. However, on signalized corridors in dense urban areas, substantial time may be lost at signalized intersections. Therefore, transit signal priority should be considered as a supporting component for the Metrobus and future BRT corridors in Mexico City. It could also be considered for other government-operated modes such as the trolleybuses and regular bus system. Signal priority is not viable for the privately owned and operated colectivo service where operations are more informal and have very frequent service. Because BRT services often operate along highly congested corridors, the impacts of signal priority on traffic on side streets would have to be carefully considered because of the possibility for increased idling emissions. Conditional priority, based upon whether the bus is on or schedule or not, would probably be the most appropriate application. Because there are no passing lanes for the Metrobus on Insurgentes, conditional priority could be help to control headways between buses, and avoiding bus bunching by giving a time advantage to behind-schedule buses.

Another issue that has sometimes arisen with respect to BRT systems in Latin America, are the negative perceptions of buses operating in platoons or convoys, whether as a deliberate operational strategy to permit a “train-like” operation, or as the result of difficulties in controlling headways between buses. According to Menckhoff, a consultant with the World Bank, referring to the 15-km Nove de Julio busway in São Paulo, which reported volumes of over 20,000 passengers per hour per direction, “Although efficient in moving people, it was perceived to have negative environmental and commercial impact by creating a ‘wall-to-wall’ line of buses, especially at intersections and some bus stops” (Menckhoff 2005, p 3). This issue has not yet arisen with regards to the Metrobús. On the contrary, one of the early problems was an insufficient number of buses to meet the demand on Insurgentes. Yet, it could become a problem depending upon the location of future extensions of the system. For example, one possibility that has been raised for the next Metrobús route is the well-known and historic Reforma Avenue. Conditional signal priority, using AVL, could be used to control the bunching of vehicles. By reducing the bunching of vehicles into platoon formation, the impact of high volume and high frequency BRT service on a corridor can be minimized.
ITS could also be used to either reinforce the exclusive use of the busways, or, in some places, as a substitute for physical barriers to separate the busways from general traffic. Several Brazilian cities have used video camera enforcement to prevent non-authorized vehicles from using the bus lanes (Menckhoff 2005, p 3). This has allowed them, in some places, to have a more open operation of BRT, where buses can leave and reenter the busway, for example, to pass other buses. In the MCMA, there have been enforcement issues, not with the Metrobús, but with the older trolleybuses, which operate on counter-flow lanes with rounded metal speed bumps to separate the lanes from general traffic, face frequent incursions into their lanes by colectivos, taxis and private autos. Video enforcement of dedicated lanes for buses and trolleybuses could ensure that there is no encroachment of the lanes for buses, and perhaps restore service levels to some of the trolleybus services in areas where there is substantial encroachment of the exclusive lanes.

Clearly, improving government-operated transit services through ITS poses substantial challenges. The challenges of considering the extension of ITS to the informal colectivo services clearly adds additional layers of complexity. However, because these services represent the majority of daily trips in the MCMA, they cannot be simply ignored. As noted by Sussman, the question is:

“How to take advantage of the positive aspects of jitney service and ameliorate the negative side effects.... Indeed, the idea of using ITS to coordinate intermodal public transportation trips, taken by passengers who might use jitneys, buses and metros to get from origin to destination, can be an important service innovation in mega-cities” (Sussman 2005, p 169).

Although ITS cannot work simply as a technology fix to what are organizational, institutional, and economic issues with the private transit operators, it can create new possibilities for service innovations and organizational change. For example, the General Director of Metrobús has emphasized the importance of the smart cards and automation of the revenue collection process as critical to supporting the organizational and institutional structure incorporating the former colectivo operators (Calderón Aguilera 2006).389

The primary air quality benefit of these technologies would be through changes in mode share, and thus reducing emissions from private vehicles, which currently represent one-third of total mobile source NOx emissions. By providing high quality service, ridership levels could be maintained or increased, with the help of supporting ITS technologies. The other benefit would be through the improved operation of the transit vehicle, in terms of fewer stops and accelerations/decelerations and less idling, therefore reducing the emission from the transit vehicles themselves.

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389 Also see Iván Sosa. 2006. “Saturan entradas del Metrobús (Metrobús entrances are saturated).” Reforma, April 25.
7.5.1.2 Traffic Flow Improvements

In Chapter 6, we saw that in four of our five US case study cities used traffic signal improvements in different forms: signal timing improvements for intersection or corridors, signal synchronization, signal interconnection, and advanced traffic signal control strategies, including adaptive signal control. We included Los Angeles' Automated Traffic Surveillance and Control system and Houston's Regional Computerized Traffic Signal System as two of the “best of” in the use of ITS for air quality purposes. Improvements to traffic flow through ITS have the potential to bring near-term emissions reductions by reducing idling and stop-and-go traffic conditions. Surveys undertaken for the 1999 Cometravi studies found that levels of service—looking at 30 major intersections and 14 corridors—founds levels of service equivalent to “F” for 73% of the intersections (adapting the 1985 US Highway Capacity Manual to Mexico City), with an average delay between 85 and 180 seconds (Gakenheimer, Molina et al. 2002, p 231). This information was collected now over 7 or 8 years ago, meaning that with the huge increase in motorization levels (over 2.3 million new cars sold in the MCMA since 1999), LOS has probably deteriorated even further. Lowering intersection delay could reduce emissions substantially by reducing this idling time. However, it should be noted that there are also limits to the congestion mitigation that traffic signal improvements can provide in over-saturated traffic conditions. In addition, the “NOx penalty” is not likely to occur, given that traffic flow improvements, under current levels of congestion, will probably not increase speeds to the point where NOx emissions will begin to rise.

According to the Integrated Program for Transportation and Roadways (PITV) released in 2002, there were 314 major bottlenecks in the Federal District; 84 of those were located in the municipality of Cuauhtémoc, one of the central areas of the DF. Researchers at the National Polytechnic Institute (IPN) in Mexico City found that 80% of the vehicles circulating in the city pass through these intersections, which included interchanges between highways such as the Anillo Periférico, Circuito Interior, and Viaducto Miguel Alemán, but also include intersections with signalized roadways.390 Particularly among the latter, signalization improvements could be used to reduce delay and stop-and-go traffic conditions.

The DF has opted for development of an adaptive control system, using SCATS, for key signalized intersections. One of the weaknesses of choosing this system is that it relies on functioning and well-placed inductive loops. However, the lack of coordination between the Secretariat of Public Security (SSP) and Secretariat of Public Works (SOS) often leads to damage to the system during road maintenance projects. Furthermore, as consultants for SSP suggested, the system is not usually functioning in its fully adaptive mode. Therefore, one consideration would be to dedicate resources toward signal optimizations, synchronization, and coordination, as well as interconnection of a larger share of signalized intersections back to the traffic control center, rather than spending the additional resources for the adaptive system.

However, in such highly congested conditions, any traffic flow improvements will also have the potential to induce additional demand (new trips or trips diverted from public transit) or divert

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traffic from other, more congested routes. Taking a “lower tech” example, beginning in the summer of 2002, a traffic flow program was put into place, which increased the number of traffic police along several of the most “chaotic” routes and intersections. Measures that were taken included towing vehicles that were illegally parked on roads and sidewalks, restriction of passenger ascent/descent for public transit, restriction of valet parking, and elimination of U-turns. Traffic police were also placed at critical intersections to manage traffic flows at signalized intersections. Travel times were found to have fallen by 30% on average on Insurgentes Avenue, where the program was first implemented (before the deployment of the BRT corridor). At the same time, traffic counts at individual intersections along Insurgentes showed that volumes increased between 10% and up to 48%. For example, at the intersection of Insurgentes and Baja California, volume increased 48% from 1,904 vehicles per hour to 2,815 (from North to South).391

7.5.1.3 Traveler Information

In Chapter 6, we found that although the use of traveler information as a measure to improve air quality was not common for our five cases, Los Angeles did make use of both transit information and multimodal traveler information as an air quality improvement measure. We suggest that multimodal information could be used in Mexico City to reduce emissions in various manners.

Mexico City traffic congestion is characterized by high variability in travel times. Because of the Federal District is the political, economic and social hub for the entire county, there are frequently events which can paralyze traffic, most notably, protests and marches, which can occur any day of the week. Furthermore, these events often occur along routes where traffic demand and congestion is highest. Incident management, utilizing traveler information, is another area where substantial near-term improvements could be made. It could provide large mobility benefits by reducing the variability of travel times, and perhaps avoid contributing to peak concentrations of ozone by minimizing the length of time that traffic is affected by incidents and accidents.

Advanced traveler information would provide greater control to travelers regarding their time-of-day, route and possibly even mode of travel. Currently, there are limited sources of information on travel times, and reporting of incidents is often unreliable. There has been substantial deployment of CCTV (172 cameras) by the DF, which can verify events and help organize responses. However, these images of problem points do not help travelers to determine travel times along an entire corridor. There is a limited deployment of loop detectors and problems with their maintenance, meaning there is limited real-time electronic data collection. Other roadside detection methods not relying on embedded loops are now available. However, a relatively low cost and robust method could be the use of automatic vehicle identification (transponders), with roadside detection, to get accurate travel times from probe vehicles. One option would be to provide information to travelers via the internet or automated phone-based services.392

391 See www.ssp.df.gob.mx/htmls/traf_prog_opeUni.html. There are no figures on the changes in average traffic flows for the entire corridor where the program was implemented.
392 Setravi currently uses a phone-based service, but relies on operators, which limits the potential volume of calls that it can handle.
While traffic information is usually the building block, and the reason for which most people might first access traveler information websites or phone-based services, it is also important to provide multi-modal information on alternate modes. Particularly with the deployment of BRT type services in Mexico City, where buses using confined corridors could have a travel time advantage over private vehicles, transit could be promoted to drivers as an alternative. For example, travel times for Insurgentes could be given along with information on approximate travel times for the same segment, but traveling via Metrobús. Although all public transit services are not yet equipped to provide real-time information through AVL, a major step would be to centralize route and schedule or average headway information in one place. Therefore, an initial set of information for a multi-modal traveler information service would include:

- real-time traffic information, with travel times and incidents;
- construction updates;
- schedule, route and fare information on all public transit services; and
- information on Hoy No Circula and other vehicle circulation restrictions.

Finally, looking at the example of cities that have established Ozone Alert programs (Tulsa was one example in our set of cases), VMS and other traveler information services could also serve as warning systems for high ozone levels, whether contingency levels or lower thresholds at which ozone presents a risk to public health. These services could be used to request voluntary actions on the part of citizens, and with the support of business, to shift travel times away from peak travel, carpool, or take public transportation.

The overall potential for air quality benefits from traveler information in Mexico City, as discussed in Chapter 2, it would depend upon the level of market penetration of information, responses to that information in terms of route switching, time-of-day shifts, and mode switching.

7.5.2 Policy and Institutional Options for Improving Air Quality through ITS

The above technology options highlight potential improvements to air quality and mobility through ITS. In this section, we will look at four policy and institutional options for improving the conditions leading to IIDAPT, based on the results of Chapter 6. As discussed in Chapter 6, there is a normative component to this approach. It assumes that it is “good” to use ITS as a measure to reduce emissions and improve air quality. We argue that Mexico City, is in many ways, similar to Los Angeles in what must be done to improve air quality, and seeking reductions wherever they may be found. Clearly improvements from ITS cannot have the same magnitude of impact as could major improvements to vehicle emission control equipment, fleet turnover, and improved fuels. However, it is also likely that improvements from vehicles and fuels alone will not be enough to reduce emissions to an acceptable level. Incremental improvements using ITS in a number of areas – traffic flow improvements, transit improvements, mitigation of the impact of incidents and events, and more intelligent trip making by travelers empowered with more real-time information – could provide important benefits. Furthermore, these benefits can also be achieved quickly and at a lower cost than many other emission reduction measures.
For the US case study cities, we identified the three most important conditions leading to IIDAPT outcomes: problem severity, dedicated resources and mutual benefits. We also added a fourth condition of new information. Although it was not a strong predictor of IIDAPT outcomes, we suggest that bettering structuring evaluations of air quality outcomes could improve IIDAPT outcomes. At least, restructuring evaluation of air quality outcomes to highlight measurable outcomes could prevent some of the perverse outcomes that were seen in the US, such as the misuse of dedicated resources (CMAQ program funding) for projects with unclear emissions benefits. With these four IIDAPT conditions, in Chapter 6, we developed a “checklist” for other cities that may want to identify changes that could be made to improve the probabilities of successful IIDAPT. We now apply these recommendations to Mexico City, taking into account the important differences (and important similarities!) between US cities and Mexico City.

- **Policy Intervention 1:** Increase the regulatory stringency for addressing air quality problems in metropolitan areas, to promote experimentation with ITS for supporting air quality goals.

Air quality in the Mexico City Metropolitan Area is currently worse than in any US metropolitan area. Yet, as described in Section 7.3.2.3, there has been a type of two-tier regulatory framework for air quality management in Mexico. First, are the public health-based national ambient air quality standards, which are exceeded on a regular basis without any apparent action, and have therefore lost their regulatory vigor. Second, are the much higher concentration levels established for “contingencies” in which immediate actions are taken to reduce emissions and exposure. Unfortunately, these contingency levels have become the de facto air quality standards, in terms of the pressure on agencies to take actions to emissions. Although there have been important reductions in the number of contingencies – with recent years having no contingencies – the number of days exceeding the national ozone standards are still extremely high (see Figure 7-7).

In Chapter 6, we suggested that a severe problem was an stimulus for innovation by public sector agencies, and that problem severity could be a function of the following:

- the extent of the physical problem,
- pressure for change or action by stakeholders,
- pressure for change or action by the general public,
- difficulties in meeting federal requirements or standards, and
- anticipation of important changes in any of the above.

Because of the decline in the number of contingency days – important sources of pressure for action – and the lack of financial or regulatory repercussions for metropolitan areas not meeting the actual federal ambient air quality standards, there is not as strong of an impetus for innovation. There is less motivation to push into a range of new transportation-based measures for reducing emissions. This does not mean that agencies are not undertaking important actions to improve air quality. Indeed, they are implementing many of the measure included in the 2002-2010 Proaire, and developing new strategies as well. However, air quality has to compete with a number of different issues, including different environmental issue, such as the emerging sense of a crisis over water quality and availability in the MCMA. With weakened regulatory
pressures for air quality improvements, it may be difficult to maintain the momentum for continued reductions in air emissions, let alone pursue innovative approaches to improving air quality through ITS.

In order to foster the use ITS in support of air quality, we suggest ratcheting up the pressure on agencies to experiment with innovative approaches to improve air quality. This could be done in two ways. First, would be to significantly lower the contingency levels to be more representative of healthy air quality conditions (i.e., closer to the national air quality standards). This would increase the pressure on agencies, in particular, transportation agencies, to seek out a greater range of new actions to improve air quality. But, it would also have the downside of having an “episodic” nature, with a focus on more immediate, short-term actions to address contingencies, rather than making sustained reductions. The second approach would be to toughen the consequences for local transportation and air quality agencies not meeting the air quality standards. As discussed in Section 7.2.3.4, there have been discussions of creating a framework similar to that of transportation conformity in the US. To be successful, this would have to be linked to possible financial consequences of delays in federal transportation funding for failure to show conformity with air quality plans.

Yet, our focus here in on promoting innovation with ITS for air quality. Therefore, without examining the possibilities for a full-fledged transportation conformity framework for Mexico, one aspect that could be useful is the requirement to consider a range of transportation control measures (TCMs). Again, TCMs are measures that reduce emissions primarily by reducing vehicle use (through transit, bicycle and pedestrian improvements, HOV lanes, ridesharing programs) or improving traffic flow. One could consider a somewhat watered-down version of the US transportation conformity requirement, where the primary focus is not on meeting emissions budgets for mobile sources by forecasting emissions from long-range transportation plans (as described in Section 7.2.3.4), but rather on strict requirements to identify and implement “reasonably available” TCMs. This would create pressures on areas to seek out emission reductions through a variety of approaches on both the transportation demand and supply side, and open up opportunities to use ITS to support air quality goals directly and indirectly.

Policy Intervention 2: Provide dedicated resources that create “slack” for innovation, in order to increase the likelihood of experimentation with ITS for air quality purposes.

While dedicated resource were available to certain projects in Mexico City utilizing ITS, in the form of carbon credits for the Metrobús, it is unlikely that this is a stable enough form of dedicated resources to spur continuous innovation and experimentation at the local level. One policy option could be the creation of a federal funding category for transportation projects with the potential for emission reductions. This would be a program analogous to that of the Congestion Mitigation and Air Quality program for federal funding in the US, where funding

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393 Reasonably available, in the US, refers to (1) the ability to advance the date by which the area will be in attainment of the air quality standards, and (2) the technological and economic feasibility of the project. See Eisinger and Niemeier (2004).
priority goes toward projects identified as TCMs. Such a program, could be administered through the Secretariat of Communications and Transportation, through Semarnat, or jointly. The benefit of managing such a program through Semarnat, is that it could be supported by INE, the research arm of Semarnat, which could provide institutional support to local governments in terms of measuring and calculating emissions benefits.

It would also be important to ensure that these are protected resources. To provide the “slack” for innovation to occur, these have to be resources that are protected from general budgetary pressures that undoubtedly exist. It would also be important to identify the appropriate size of this dedicated resource. It would have to be large enough to support multiple innovative projects for emissions reductions through transportation-based measures, but not too large that it takes away significant funds from perhaps less innovative but basic transportation investments, such as ensuring adequate maintenance of existing transportation infrastructure.

- **Policy Intervention 3: Identify areas of mutual benefits – and areas of potential conflicts – with regards to the interests and agendas of key agencies, in order to foster cooperation on ITS innovations for air quality.**

In the five US case cities, and in Mexico City, we saw mutual benefits from using ITS for air quality were defined in large part by the existing preferences for major transportation investments. Attempts to use ITS for air quality would be successful, if it supported the preferred investments for both transit and roadway. They would be unsuccessful if it would undermine the ability of agencies to make the case for their preferred investments. Therefore, a policy entrepreneur wanting to use ITS for air quality, would have to carefully assess how key political actors and agencies may react, and whether they would see this as in their interests, or as supporting their broader agendas.

For example, take the case of the Second Stories. The Mayor, who has generally had a strong focus on class differences and has often portrayed himself as the champion of the lower classes, would probably not be in favor of congestion pricing for the new facility. He probably would see charging a toll for the Second Stories as letting the “rich” buy improved mobility, while letting the poor languish in traffic. One option for incorporating ITS would have been to use a multi-modal managed lane concept, in which at least one of the lanes of the Second Stories would be dedicated to HOT lanes and express buses. The focus could have been on providing substantially improved travel time to buses and HOV vehicles, while allowing single occupancy vehicles to buy-in to the lane if desired (using electronic toll collection). The revenue from the HOT lane toll could be used to support the express bus operations. As it stands now, the

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395 In fact, this concept of a “high-speed” left lane for express public transportation and carpools, was apparently considered at one point. However, it is not clear whether this, or combination with a tolled option, was ever seriously considered. Because there was pressure to finish and inaugurate the Segundos Pisos during the administration of Mayor López Obrador, it is conceivable that this option was abandoned because of the complications in adding a more complex operational component to a major infrastructure expansion project. See [www.fimevic.df.gob.mx/sanantonio/sa_movilidad.htm](http://www.fimevic.df.gob.mx/sanantonio/sa_movilidad.htm) (in Spanish). Last accessed June 18, 2006.
Segundos Pisos provides greater mobility only to private automobile users, thus providing little benefit to the majority of the population that still uses public transportation.

Another option could be to create an institution that had an interest in identifying and promoting ITS as a tool to better manage the transportation system and its impacts. The Metropolitan Planning Organizations in the US (particularly the MPO of Houston), were often important champions of ITS, and were also charged with the responsibility to both develop the transportation plan and assess its conformity with air quality objectives. In Los Angeles, the MPO and the air quality management district created a non-profit organization to support advanced technologies for air quality improvements. This could provide an argument for incorporating the functions of the Metropolitan Transportation Commission (Cometravi) into the Metropolitan Environmental Commission (CAM). This would combine the mobility objectives of Cometravi with the environmental and air quality objectives of CAM.

However, in order to incorporate ITS and operations-based improvements into the mix of measures to improve air quality, greater participation is also needed from agencies such as the Secretariat of Public Security. Operational improvements – such as traffic signalization, VMS, and traffic control centers, which are primarily the responsibility of the Secretariat of Public Security – need to be better coordinated with the traffic flow improvements made through physical changes. It is indicative of the fragmentation between Setravi, the Secretariat of Public Works and Services, and the Secretary of Public Security (see Table 7-4 above), that the program of “100 Actions to Improve Roadway Traffic in Mexico City,” did not incorporate any signalization improvements or other ITS-based operational improvements (Gobierno del Distrito Federal 2005). The lack of coordination between operations projects and physical infrastructure projects often directly undermines the efficiency of the projects being undertaken. For example, many of the inductive loops that are critical to the operation of the adaptive signal control system of the Secretariat of Public Security, were damaged during repaving projects undertaken by the Secretariat of Public Works and Services. By continuing to sideline the role of operations and ITS, it will be quite difficult to innovate and experiment with ITS in a way that improves air quality outcomes.

- **Policy Intervention 4: Restructure assessments and dedicated resources into a more iterative process of experimentation and evaluation, in order to increase adaptation of ITS technologies to improve air quality outcomes.**

The federal funding or dedicated resources described above would need to be coupled to quantification and some reasonable level of “proof” of the air quality benefits achieved. Contrasting this with the US experience with CMAQ evaluations, which were done ex-ante to determine project eligibility, a program of “paying” for demonstrated emissions reductions for completed projects could increase the rigor with which those assessments are done. For example, with the Metrobús, the project was implemented without having received prior monies through the sale of carbon credits, which were sold once the systems was operational. If this were managed through INE and SMA, it could be used to build up a base of information to compare similar deployments in other cities.
7.6 CONCLUSIONS

In analyzing the conditions leading to IIDAPT and actual IIDAPT outcomes in Mexico City, we saw similar themes that emerged in our analysis of five US cities. Average IIDAPT levels and range could be predicted by the seven conditions in the IIDAPT framework. Furthermore, while the context of Mexico City differs substantially from that of the US case study cities, ITS deployments for air quality would also reflect preferences for large-scale investments. It also highlighted that problem severity, mutual benefits, and dedicated resources were not only important for predicting and explaining IIDAPT outcomes, but could be used to develop concrete recommendations for improving the possibilities for successful IIDAPT. Therefore, our IIDAPT framework can be fruitfully applied to a non-US context, albeit with a continued focus on ITS technologies and air quality.

In the next chapter, we draw more general conclusions regarding the IIDAPT framework and what we learned from its application to (now) six cities. We will also consider whether it can be extended beyond the domain of ITS and air quality. We will also look at broader implications for the literature on innovation in government, multi-agency cooperation in technology deployment, and the management of socio-technical systems and their impacts in society. We now turn to our final chapter.
8.1 REVIEW OF RESEARCH QUESTION AND MOTIVATION

The integration of information and transportation infrastructures is expected to transform modern transportation systems. Indeed, some have suggested that “the social trend that is coming to have the greatest influence on transportation is the growing role of information processing and telecommunications in modern society” (Wachs 2002). While many of these transformations will have positive effects on mobility and accessibility, economic growth and development, and overall quality of life, negative outcomes are also “certain with this new transportation enterprise” (Sussman 2005). Even before the advent of the new era of information and communications technologies, the environmental challenges arising from the production and use of the transportation system – air pollution, water quality deterioration, habitat fragmentation, loss of wetlands and open space – were considerable. The emerging question is, what consequences will integration of the information and transportation infrastructures have for the environment? Will it intensify current trends or provide entirely new pathways for more environmentally sustainable mobility and accessibility?

This thesis explored the linkages between Intelligent Transportation Systems (ITS) – the application of information and communication technologies (ICT) to the surface transportation system – and the environment specifically, urban air quality. We began with a practical question: how does ITS improve/degrade air quality? There is debate among practitioners, academics, and decisionmakers regarding whether ITS will have a beneficial or detrimental impact on air quality and other facets of environmental quality. This has led to competing visions of ITS. The more dismal vision anticipates ever increasing dependence upon the private automobile, with advanced technologies used to make the most efficient use of available infrastructure to accommodate the private automobile – to the exclusion of public transportation, non-motorized transport, and more accessible and livable spaces. The more optimistic vision looks at the possibilities of using ITS to better manage transportation systems and the externalities associated with those systems. This vision foresees a more information-intensive transportation system that can better serve the needs of communities, and provide a broader range of mobility options beyond the single-occupancy private automobile, enhancing both mobility and the environment.

This debate reflects two sets of uncertainties. First, there are uncertainties in the physical system. In Chapter 2, we highlighted some of these uncertainties: how emissions factors are affected by speed and acceleration profiles, how ITS affects speed and acceleration profiles, whether ITS can lead to modal shifts between public transit and private automobiles, and other uncertainties. In Chapter 3, we then looked more broadly at the system-level uncertainties, including the issue of induced demand. Here, we considered, even if we fully understand the impacts of individual ITS technologies, how do we begin to grasp the interactions of multiple ITS deployments?

Second, there are uncertainties on the organizational and institutional side. These issues have been largely unexplored in the literature on ITS and the environment. The question relates to how organizations can and will deploy, use, manage and adapt ITS technologies. Which technologies will they use, and to what ends with they use them? Will they innovate with ITS in
a manner that attempts to either maximize the potential air quality benefits or minimize negative air quality impacts? These two contrasting visions of ITS underscore the extent to which environmental impacts depend not upon the technology itself, but upon how these technologies are deployed and used. Indeed, we suggest that either one of these visions could emerge. The goal of this research is to identify the conditions that could lead to the more optimistic vision.

Because we were interested in ITS for both mobility improvements and environmental improvements, what emerged was the issue of how public sector agencies could achieve synergies between these two objectives. More specifically, we saw that environmental benefits could “piggyback” on the core mobility objectives that motivate the majority of ITS deployments. Therefore, we were interested in under what conditions public sector organizations achieve synergies between mobility and air quality goals through the deployment of Intelligent Transportation Systems (ITS) technologies.

In order to identify the appropriate set of conditions, we first developed the concept of Integrated Innovation, Deployment and Adaptation of Public Technologies (IIDAPT), to represent the concept of how public sector organizations cooperate in the deployment, assessment and adaptation of new technologies for multiple policy objectives. This concept is more fully described in Section 8.2.2. Based on the literature reviewed in Chapter 4, we identified seven conditions leading to higher or lower levels IIDAPT, in which agencies achieve (or do not achieve) multiple policy benefits for air quality and mobility through ITS. The full IIDAPT framework is shown here.
In the following sections, we will discuss how we tested the validity of this framework, using case studies of five US cities and Mexico City. For each city, we closely examined how, in fact, ITS is being employed for the purposes of both mobility and air quality, and how well the seven conditions shown in Figure 8-1 could predict and explain those outcomes.

In Section 8.2, we will review the main findings from this analysis, with a focus on the following research questions that were presented in Chapter 1:

*How does ITS improve/degrade air quality?*

*Can we develop and test/validate a theoretical framework for predicting what levels of IIDAPT will occur?*

*What conditions lead to higher/lower levels of IIDAPT in using ITS to support air quality goals in addition to mobility goals?*

Returning to the base of literature that was used to development the theoretical framework for IIDAPT, we will ask if the cases provided new insights for the literature dealing with innovation in government, cooperation between agencies for multiple policy benefits, and assessment and adaptation of technologies. This will address the following research question.

*What are the contributions to the literature?*

We will then focus on the question of how ITS is being used by US cities, in practice, to support air quality objectives, or not.

*Are ITS technologies being "shaped" to promote air quality objectives, and if so, how?*

Following this question of what is actually occurring in US metropolitan areas regarding the use of ITS for air quality benefits, and based upon what we learned about the seven conditions leading to higher/lower levels of IIDAPT, when then turn to the key policy recommendations of this thesis in Section 8.3. This will address our final research question.

*Can we then use this framework to provide policy recommendations for fostering higher levels of IIDAPT?*

We will then end with a discussion of possibilities for future research and refinements and extensions to this framework.
8.2 FINDINGS

In this section, we will review the key findings according to the questions we posed in the introduction to this thesis. This will then point us toward specific policy recommendations, for both US cities and Mexico City (Section 8.3), as well as areas for future research (Section 8.4).

8.2.1 How does ITS improve/degrade air quality?

At the beginning of this thesis, we posed the question of how ITS improves or degrades air quality. In asking this question, we found that we were essentially setting up a strawman. Indeed, for the remainder of the thesis, we argued that the air quality impacts of ITS are not immutable products of the technologies itself, but rather are contingent upon how those technologies are applied and used by the organizations deploying and managing them.

Nonetheless, the debates over the air quality impacts of ITS are framed by important scientific and technical uncertainties. There are important insights to be gained from reviewing the literature on the ways in which ITS can improve air quality, and how ITS can also lead to a degradation of air quality. In Chapter 2, we comprehensively reviewed the literature on ITS and air quality benefits for three major subsystems: advanced traveler information systems (ATIS), advanced transportation management systems (ATMS), and advanced public transportation systems (APTS). In this chapter, we also defined and characterized new energy and emissions subsystems for ITS technologies, which would be capable of measuring, monitoring and reducing mobile source emissions. Finally, we discussed the trends toward technologies that “manage” travel not at the level of infrastructure or vehicles, but at the level of individual travelers.

Although many fundamental questions still remain unresolved, some preliminary observations could be made. Improved traffic flows from ITS seem to provide modest reductions in HC and CO, although NOx emissions are generally more difficult to reduce, as increased flow speeds disproportionately raise NOx emissions factors after about 30-40 mph, and NOx idling emissions are low (meaning that reducing idling is less effective for NOx reductions than for HC and CO reductions). The traffic smoothing aspect of ITS is important, and reductions in hard or sustained accelerations offer the potential to reduce emissions.

However, since NOx is not as significantly affected by the power enrichment that occurs during hard accelerations (HC and CO are more strongly affected), reducing these hard accelerations will do less in the way of NOx. For example, while electronic toll collection (ETC) may reduce hard accelerations events, ramp metering may actually introduce additional hard accelerations, as vehicles quickly accelerate from zero to freeway speeds. Therefore, ramp metering seems to be a better NOx strategy than for HC or CO, although if average freeway speeds are increased substantially, NOx will begin to rise again. Therefore, different strategies may present tradeoffs between NOx reductions and CO and HC reductions.

The quality of studies for advanced traffic signalization is highly variable. There seems to be some potential for emissions reductions by smoothing traffic flows. Indeed, benefits from
smoothing traffic flow may be underestimated where average speeds are used, because these studies are not capturing the changes in accelerations and idling. However, there may also an overestimation of the benefits where the question of induced demand has not been adequately considered. While the issue of induced demand – the generation of new and/or longer trips (higher demand for travel) due to lower travel times (a lower “cost” of travel) has been increasingly studied for traditional physical infrastructure expansion, it is still poorly understood for operations-based traffic flow improvements.

Air quality studies of ITS improvements to public transportation have been relatively narrow, focusing on changes in the bus operations along a particular route, and changes in emissions that result from fewer stops or increased speeds. Some work has been done to assess to what extent different types of signal priority to transit affect regular traffic, with inconclusive results. Impacts on side traffic depend upon the type of priority given to transit, i.e. whether conditional or not, upon factors such as schedule adherence. However, the emissions outcomes from more systemic changes to the transportation system, such as mode shift due to improved service quality and the image of the transit system, have not been well explored.

Finally, the role of advanced traveler information seems to indicate a balancing act between the congested route and the non-congested alternative, in the case of information regarding incidents. Market penetration, compliance rates, and the severity and duration of the accident determine whether ATIS can distribute traffic flows efficiently, or lead to “overreaction” and congestion of alternate (usually arterial) routes. In the case of recurring congestion, ATIS does seem to improve network performance. However, it also opens up the possibility of inducing demand through reduced travel times. Again, as with APTS, the potential for ATIS to change mode share and the possibilities for induced travel from ATIS have not been seriously examined. There is also a serious gap in assessment of the benefits of multi-modal information, which show not only traffic conditions, but also transit information for those travelers that may not be accustomed to using public transit, and information on carpool or vanpooling options that can reduce travel time by allowing access to HOV facilities.

Through the review of existing studies on the air quality impacts of ITS, we identified some important issues. Some of the research needs we found are highlighted below.

- Better understanding of how ITS changes the vehicle modal activity distribution (i.e. how much time is spent cruising, acceleration/deceleration, or idling) on a second-by-second basis from both field data and simulation modeling.

- Additional field measurements – monitoring individual vehicle emissions under real-life operating conditions – to develop emissions factors for instantaneous speed and acceleration profiles (i.e. grams per second as a function of speed (mph) and acceleration (mph/sec)). These field measurements need to span a wide range of vehicle characteristic to be able to represent diverse vehicle fleets, including for example, high emitters, hybrid vehicles, public transit vehicles, etc.
- Field measurements to monitor before-and-after pollutant concentrations along ITS-modified corridors, for comparison with simulated emissions levels.

- Analysis of the relative impact of public transit ITS applications on transit ridership and overall mode share.

While the studies reviewed above have advanced our understanding of the localized impacts of single ITS deployments, the system-wide impacts (including all modes) from multiple ITS deployments are far from clear. In Chapter 3, we presented a qualitative system approach for mapping out the possible air quality impacts from deploying multiple ITS applications. This highlighted the importance of considering issues of induced demand and the mix of ITS applications, which could have more important long-term repercussions for the evolution of the transportation system. We found that the following additional issues remain to be addressed by researchers.

- The extent to which traffic flow improvements from ITS lead to induced demand, and the relative size of emissions reductions from changes in vehicle modal activity compared to emissions increases from higher VMT.

- If the “mix” of metropolitan ITS deployments – whether more heavily oriented toward transit, traffic, information, etc. – can change the modal split between transit, signal occupancy vehicles, ridesharing, and non-motorized transportation (walking and biking).

- Related to the previous point, whether and how ITS applications can be used to improve “in-vehicle efficiency” through Information-based Transportation Strategies (IbTS) through transit and alternative modes such as ridesharing and carsharing.

More importantly, these issues point us back to the idea that the air quality impacts of ITS will depend upon how those technologies are used by the agencies that are deploying them. These are not solely technical uncertainties, but uncertainties regarding the intentions, motivations, agendas, and objectives of organizations. We therefore turn to our IIDAPT framework to address these questions.

### 8.2.2 Can we develop and test/validate a framework for predicting levels of IIDAPT?

In Chapter 4, we defined and articulated a concept of Integrated Innovation, Deployment and Adaptation of Public Technologies (IIDAPT). Stated briefly, IIDAPT occurs when:

Public sector organizations cooperate to adopt and use new technologies in support of multiple policy goals. This process of innovation is iterative, as agencies assess impacts and adapt technologies to new information on outcomes.

Breaking down the IIDAPT definition in more detail, the term integrated suggests the active pursuit of multiple public policy goals that pertain to more than one public sector agency. This may be through active involvement and cooperation of several (at least two) agencies in the design and deployment of a new technology, or the more unilateral initiative of one agency to
support the organizational and policy goals of other agencies (in addition to their own goals),
during the process of innovation and deployment. Deployment indicates that we are focusing
only on technologies that actually reach the operational stage, not technology development,
research or invention (although those may be activities leading up to deployment). We use the
term innovation with two ideas in mind. First, there is innovation in the application of advanced
technologies (such as ICT) to new sectors (such as transportation). Second, there is another layer
of innovation when these advanced technologies (ICT), are applied to a new sector (transportation),
in support of non-traditional goals (air quality). Therefore, innovation, as we
are using it here, is a combination of technological innovation, with the adoption and adaptation
of advanced technologies, and policy innovation, in using these technologies in novel ways for
reaching additional policy goals. We also use the term adaptation to refer to the process of
continual assessment of technologies and their impacts, using the information that is generated
during the evaluation process to improve and modify the already implemented innovation, and/or
designs for future deployments. Finally, we use the term public technologies to indicate that
these are technologies deployed primarily by public sector organizations (although there may be
additional cooperation and support from other organizations), and that the technologies are
intended to provide public benefits or public goods. In the case of this research, those public
benefits are mobility and accessibility and air quality.

8.2.2.1 Measuring IIDAPT

We also argued that IIDAPT could be considered along a scale, from lower to higher levels of
IIDAPT. In order to better describe, understand, and ultimately measure actual IIDAPT
outcomes – in this thesis, for the use of ITS to meet both air quality and mobility goals – we
focused on four activities that support IIDAPT. These activities were identified based on the
literature reviewed in Chapter 4. We suggested that cooperation and innovation are the two core
activities, while assessment and adaptation are two supporting activities that would indicate
higher levels of IIDAPT. Low and high levels of these four activities, thus contribute to lower
and higher levels of IIDAPT. This is shown in more detail in Table 8-1.
Table 8-1 Qualitative Scale for IIDAPT

<table>
<thead>
<tr>
<th>Core Activities</th>
<th>Supporting Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooperation</td>
<td>Innovation</td>
</tr>
<tr>
<td>High</td>
<td>More than one agency actively engaged in the design, deployment and/or operation.</td>
</tr>
<tr>
<td>Low</td>
<td>More than one agency indirectly involved or playing a supporting role in the design, deployment and/or operation.</td>
</tr>
<tr>
<td>None</td>
<td>No cooperation.</td>
</tr>
</tbody>
</table>

For the case study work, we used the above table to develop a numerical ranking for IIDAPT levels for individual ITS technologies deployed with air quality benefits as an important, albeit secondary, policy objective. This numerical scale was applied to individual technologies from ten ITS application areas for each case study city.

Table 8-2 Numerical Scale for IIDAPT

<table>
<thead>
<tr>
<th>Core Activities</th>
<th>Supporting Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cooperation</td>
</tr>
<tr>
<td>High</td>
<td>2</td>
</tr>
<tr>
<td>Low</td>
<td>1</td>
</tr>
<tr>
<td>None</td>
<td>0</td>
</tr>
</tbody>
</table>

We then scaled up from individual technologies to the metropolitan level, which gave us two measures: average level and range (see Table 8-3). We also took another independent measure of intensity. Although for the individual case analyses, several measures of intensity were used, for the cross-case comparison, we used a more standard measure based on the share of Transportation Control Measures (TCMs) that were ITS or ITS-enhanced projects (see Table 8-4). These three measures reflected the (1) average IIDAPT level in the use of ITS for air quality, (2) the diversity or range of ITS technologies used in support of air quality goals, and (3) the intensity of use of ITS compared to other mobile source emission reductions measures.

Tulsa was the exception. Because there was not a similar State Implementation Plan with TCMs, as for the other metropolitan areas, we used the share of ITS-based projects for the full Early Action Compact (EAC).
Table 8-3 Scaling up to the Metropolitan Area

<table>
<thead>
<tr>
<th>ITS application areas</th>
<th>Representative technology</th>
<th>IIDAPT scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arterial traffic flow improvements</td>
<td>project</td>
<td>#</td>
</tr>
<tr>
<td>Freeway management strategies</td>
<td>project</td>
<td>#</td>
</tr>
<tr>
<td>Freeway traveler information</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>Transit information</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>Multi-modal information</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>Transit operational improvements</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>Transit fare payment systems</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>Rideshare support</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>Demand management/pricing</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>Other applications</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Average level (0-6) = Average across application areas
Range of IIDAPT (0-10) = Number of application areas

Through this exercise, we found that we could not only articulate the concept of IIDAPT, but also develop an approach for measuring actual IIDAPT levels. First, we measured IIDAPT at the level of individual technologies, and then aggregated the results of the analysis of individual technologies to the metropolitan level, by deriving the three measures of IIDAPT described above: average level, range, and intensity. The product of these three measures was then taken to give an overall IIDAPT level. Thus, we were able to articulate the concept of IIDAPT in a way that could be empirically measured.

8.2.2.2 Identifying the Conditions Leading to IIDAPT

Having developed an approach to describe and measure IIDAPT, we then faced the challenge of identifying the conditions leading to IIDAPT, and establishing a testable framework for IIDAPT. This framework, which forms the basis for the case analysis in this thesis, was presented above in Figure 8-1. In order to derive a set of conditions leading to IIDAPT that could be tested, we turned to the literature on innovation, cooperation, assessment and adaptation, which is presented in the literature reviewed. We drew these conditions from our synthesis of the literature on organizational theory, public administration and political science, specifically those lines of research dealing with innovation in government, cooperation for environmental management, and technology assessment and adaptation. These conditions were expressed in Chapter 4 as seven propositions, based on the literature reviewed. We summarize these below.

Proposition 1: Public sector organizations will innovate in response to changes in the external environment, and the level of innovation will be relative to the severity of the problem.

Proposition 2: The level of an agency’s internal resources, in terms of funding, staffing levels, and education and training of staff, increases the capacity to adopt and deploy technological innovations.
Proposition 3: **Dedicated resources** to specific categories of programs or project will lead to more innovation in that area.

Proposition 4: **Lower cost innovations** will be more likely to be deployed.

Proposition 5: Cooperation between agencies is more likely if there are perceived **mutual benefits** to be gained from the innovation.

Proposition 6: The likelihood of integrated innovation falls as the **number of organizations** with a stake or role in the innovation increases.

Proposition 7: The availability of **new and better information** will lead to adaptation of programs and projects to improve outcomes.

The IIDAPT framework, Figure 8-1, shows how each of these conditions affect cooperation, innovation, assessment and adaptation, the four activities supporting IIDAPT. However, we also recognized the possibility for interactions between the conditions. These secondary links were identified by dotted lines in Figure 8-1. For example, rather than mutual benefits deriving from the fact that certain innovations can achieve multiple policy objectives for agencies, the mutual benefits could become embodied in the dedicated resources (i.e. CMAQ funds) that were created to solve certain problems. In other words, innovation may be motivated not by the need to address important problems (air quality), but how best to access the funding pool (federal CMAQ funds) created to address those problems. The advantage of the case study approach is that these indirect interactions could also be explored.

8.2.2.3 Testing the IIDAPT Framework

Now that we have described how actual IIDAPT outcomes were measured, and how the conditions leading to IIDAPT were developed, we now turn to the question of whether the IIDAPT framework can be tested, and what the results of this testing were.

In-depth case studies of five US metropolitan areas were undertaken to analyze if and how cities are actually deploying ITS in ways that also support air quality goals in addition to mobility goals. These metropolitan areas were chosen with the intention of representing a range of possible IIDAPT levels. This differs from other studies of innovation in government in which cases of known innovations/innovators are analyzed to understand the factors leading to successful innovation. We intentionally added two cases, Orlando and Tulsa, which were anticipated to have low levels of IIDAPT (perhaps even zero) because of their status as attainment areas (i.e. no air quality problem), and because of a low base of ITS deployment in the case of Tulsa (see Figure 8-2). Los Angeles and Houston were more obvious cases of a high potential and need to use ITS for air quality benefits. Boston, a case in the middle, was less certain as to what its outcome would be. It is important to note that while the cases were chosen because they were anticipated to reflect a range of IIDAPT levels, actual IIDAPT levels were not known before the case study work and quantitative analysis were completed.
We tested each individual case – Houston, Los Angeles, Boston, Orlando and Tulsa – to determine to what extent the predicted IIDAPT levels, based upon the seven conditions, matched with the actual IIDAPT levels. Again, actual IIDAPT levels were an aggregate measures, representing the product of average level, range, and intensity. The five case comparison is presented below.

**Table 8-4 Predicted versus actual IIDAPT levels**

<table>
<thead>
<tr>
<th></th>
<th>Houston</th>
<th>Los Angeles</th>
<th>Boston</th>
<th>Orlando</th>
<th>Tulsa</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Predicted level</strong></td>
<td>High</td>
<td>Med-high</td>
<td>Medium</td>
<td>Very low</td>
<td>Low-medium</td>
</tr>
<tr>
<td><strong>Actual level</strong></td>
<td>5.2</td>
<td>4.0</td>
<td>2.3</td>
<td>0</td>
<td>2.3</td>
</tr>
<tr>
<td><strong>Average level</strong></td>
<td>High</td>
<td>Med-high</td>
<td>Medium</td>
<td>None</td>
<td>Medium</td>
</tr>
<tr>
<td>0-6</td>
<td>4.5</td>
<td>3.8</td>
<td>2.9</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td><strong>Range</strong></td>
<td>4</td>
<td>8</td>
<td>4</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>0-10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Intensity</strong></td>
<td>29%</td>
<td>13%</td>
<td>20%</td>
<td>0%</td>
<td>26%</td>
</tr>
<tr>
<td>% of all recent TCM projects</td>
<td>of all post-2000 TCMs</td>
<td>of all post-2002 TCMs</td>
<td>of SIP transit commitments</td>
<td>of all EAC projects</td>
<td></td>
</tr>
</tbody>
</table>
As seen in Table 8-4 and Figure 8-3, the distribution of IIDAPT levels was closely predicted by the seven conditions. Tulsa appears with a higher than expected level of IIDAPT, although that can be explained in part by the way in which we measured problem severity. By measuring problem severity as the official federal designation for attainment with the 1-hour ozone standard, we underestimated the response to local and state agencies’ anticipation of possibly falling out of attainment with the new 8-hour ozone standard.

We are careful not to suggest categories of “high” or “low” for the actual levels for the case studies. Theoretically, the highest actual IIDAPT level could be 60. Of our five case study cities, and for the time period analyzed, Houston had the highest IIDAPT levels, at 5.2. Because there are only five data points, we are also careful not to overstate the implications of this first cut at testing the framework, and the apparently good correlation between predicted and actual levels. However, we are confident that the results presented here support the validity of the IIDAPT framework, and in particular, the general predictive power of the seven conditions leading to IIDAPT.

Again, this testing used an aggregate measure for comparing actual IIDAPT levels to predicted levels. One possible weakness of this approach is that it combined different dimensions of performance: average IIDAPT, range, and intensity. However, looking at Table 8-4, we also saw that the three measures of IIDAPT did not covary. For example, Houston had a high average IIDAPT level and intensity, but low range. Los Angeles, was almost the opposite with a higher

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397 This would require an average IIDAPT level of 6, range of 10, and intensity of 100% (giving a summary level of 6 x 10 x 1). For the measure of intensity, this would mean that all Transportation Control Measures would be ITS or ITS-enhanced. Currently, intensity is closer to 10-20% in most cities, although this can vary from one time period to another.
range, and lower average IIDAPT level and intensity. We discussed possible reasons for this in Chapter 6 (see Section 6.3.1). For example, it appeared that the number of agencies, not a good predictor of actual IIDAPT using the aggregate IIDAPT measure, may have had an impact on the range. Los Angeles having a higher number of agencies and more decentralized decisionmaking process, had a much higher range of IIDAPT for ITS and air quality, perhaps because of the greater number of opportunities for experimenting with ITS for air quality purposes. Houston, a more centralized planning environment with a smaller number of agencies, particularly for the city’s population and size, had a low range, perhaps because efforts were concentrated in only a few categories of IIDAPT. The next steps in testing the predictive value of the framework would be to test it for these three disaggregated measures, possibly for a larger number of cases, to see how the seven conditions affect these disaggregated measures, and whether they tend to covary or not.

Further validation of the framework could also require breaking out these aggregate measures – which are aggregated across different ITS technology application areas – and testing the predictive value of the model with respect to these application areas or subgroups (for transit, traffic, information, and demand management). This would also allow us to examine IIDAPT on a mode by mode basis. For example, in Chapter 6 and 7, we often saw mutual benefits defined in terms of agency preferences for operations-based strategies versus more capital-intensive physical expansions: light rail versus bus rapid transit, ITS-based freeway management versus widening/expansion, more dynamic rideshare matching versus HOV-lane expansion or HOT lane conversion, and so on. Therefore, further testing could show how mutual benefits and cost determine the average levels of IIDAPT within a specific mode.

In summary, we found that not only could we develop and test a concept and theoretical framework for IIDAPT, but that the theoretical framework performed well in predicting actual IIDAPT levels. It also points to areas for further testing of the framework at a more disaggregated level.

8.2.3 What conditions lead to higher/lower levels of IIDAPT in using ITS to support air quality goals in addition to mobility goals?

We tested seven conditions that we hypothesized would lead to higher or lower levels of IIDAPT. The strongest predictor of IIDAPT was problem severity. As problems become more pressing, as for Los Angeles and Houston, we saw more innovation and IIDAPT as those cities struggled to deal both with congestion and air quality. This confirms earlier studies of innovation in the public sector, that problem severity is a key condition leading to innovation. However, it should be stressed that for our five cases, the perception of problem severity is not necessarily based on the physical problem (i.e. parts per million of ground-level ozone), but rather on the regulatory pressure to address that problem.

We defined mutual benefits, in this case, as the requirement to meet transportation conformity requirements – for example, implementing transportation control measures (TCMs) and meeting mobile source emissions budgets. This suggested there would be mutual benefits to transportation agencies and air quality agencies from finding synergies between ITS deployment
goals and related mobility improvements (both for individual drivers and transit users), and air quality goals. Therefore, as a first cut in identifying mutual benefits, we suggested that agencies define their agency goals in relatively simple terms as follows. Air quality agencies want to improve air quality, presumably in the most efficient manner. Transportation agencies want to improve mobility, again, in the most efficient manner, and will “piggyback” air quality goals on mobility goals if it builds support for their ITS deployments. Thus, if ITS can be deployed to accomplish both mobility and air quality objectives, it can create mutual benefits between agencies. Overall, the predictive power of using this condition was fairly good. Agencies did seek out TCMs that took advantage of existing/planned improvements from ITS, as a seemingly “win-win” solution, and used CMAQ funds for ITS technologies that could improve air quality. Yet, it is interesting to take note of instances when agencies did not take advantage of ITS projects that, in these relatively simple terms, could be considered to provide mutual benefits. We described some of those cases in Chapter 6. The condition of mutual benefits, as described here, was a good predictor of overall IIDAPT levels. However, by examining the cases in greater depth, one could also uncover interesting outcomes in how mutual benefits and cost played out together. We discuss this finding in Section 8.2.4.2.

Dedicated resources illustrated another condition that worked well as a predictor of IIDAPT levels. As we could see, CMAQ funding in most cases did provide a “slack” resource for experimentation with ITS and other measures for reducing mobile source emissions. Also, as we suggested, dedicated resources can also reinforce the sense of mutual benefits, by providing a monetary incentive for transportation agencies that might not otherwise have an interest in looking at the air quality impacts of their transportation management strategies. Particularly for Houston and Los Angeles, the CMAQ program seemed to enable innovations that might not have been undertaken otherwise. As suggested in Figure 8-1, the dedicated resources therefore reinforce or create new sources of mutual benefits.

Therefore, this research showed that innovation and deployment of new ITS technologies for air quality purposes was influenced most strongly by (1) the severity of the air quality problem and the federal regulatory requirements to address that problem, (2) the mutual benefits that could be created by identifying synergies between mobility and air quality, and (3) dedicated resources that create a source of “slack” resources for non-traditional activities. Yet, the testing of our framework also revealed some more subtle dynamics, which are discussed in Section 8.2.4. And, as noted earlier, testing the framework at a more disaggregated levels, could provide additional evidence of which conditions have the strongest influence on IIDAPT levels, and whether they affect range, average level, or intensity.

8.2.4 What are the contributions to the literature?

Having tested the IIDAPT framework, we can also ask whether this exercise provided us with new insights regarding the literature on cooperation, innovation, assessment and adaptation, which was used to develop the seven conditions for IIDAPT. We identify four main areas of contributions, while pointing back to the seven propositions outlined in Section 8.2.2.2. Again, these results are based on the case of ITS and air quality, and the results from testing the IIDAPT framework for five US cities and Mexico City. Therefore, while the research provides important
findings, we warn against generalizing these results too broadly for other areas without further testing of the framework. This will also be discussed below in the section on future work.

8.2.4.1 Technology Deployment as Local Government Innovation

Contrary to the often pessimistic outlook of organizational theory, innovation in government, specifically, technological innovation, can and does occur in the absence of a crisis, when heightened public and political attention and pressured is focused on the need to immediately or urgently resolve a problem. We also found that the deployment of new technologies is an important public sector innovation that occurs in response to the severity of the problems being faced. This result is important, and optimistic from the viewpoint of the efficacy of more stringent federal regulations in spurring innovation by local governments. Clearly, Los Angeles has made very important progress in reducing ozone levels. But, even with the waning sense of an acute crisis (from the physical standpoint)\(^{398}\) the regulatory pressures stemming principally from the Clean Air Act Amendments continually stimulate innovation. In the absence of a “crisis” due to the physical problem (concentrations of ozone), regulatory changes can and do create a type of organizational “crisis” for the organizations that will struggle find ways to continue to meet regulatory requirements. This confirms earlier studies, that have challenged what was for long the conventional wisdom – articulated most strongly by Wilson – that public sector innovation occurs primarily in response to major crises and public failures, and that even under crisis, innovation may not occur. As noted by Borins:

“If public management innovation were solely the result of crises, we would likely conclude that public sector organizations are characterized by uncaring people who do not act until problems become crises, or they are gridlocked systems that do not permit actions until problems become crises. In fact, we have seen that, in the majority of cases, public servants were able to act to resolve problems before they become crises, or to take advanced of opportunities to deliver new services or to deliver existing services more efficiently.” (Borins 1998, p 47).

On a different point, this research contributed to studies of innovation in government, by placing local innovation in the federal context. This research looked at innovation at the metropolitan level – including city, county, and state agencies. But, we identified federal air quality regulations and the requirements for transportation conformity as factors that can intensify the definition of a “problem” by local/state governments (see Proposition 1). Innovation at the local level can be triggered by the tightening of regulations at the federal level. Furthermore, federal resources dedicated to certain non-traditional activities can also spur innovation at the local level (see Proposition 3). The CMAQ program provided a source of dedicated or “slack” resources for agencies to pursue innovation with new technologies. While some studies of innovation have looked at the states as 50 laboratories for policy innovation, they generally assume that innovation means the states are going beyond the federal requirements, for example, for environmental protection. This study shows how innovation can occur as a result of local and state governments attempting to meet federal requirements for environmental protection.

\(^{398}\) For example, highly visible pollution episodes with very palpable health effects on the general population, such as those that occurred in the 1950s in Los Angeles.
Active cooperation between public sector agencies, even on technologies presenting possible synergies, is difficult and not common. Because innovations with ITS for air quality do not take place in a vacuum, they will be competing with other projects both for mobility and for air quality. An agency's interest or preference to deploy ITS with the additional objective of air quality improvements depends on whether it fits, or not, with the agency's interests. Because it might be seen as competing with other projects that might be higher priority for the agencies, our condition of cost also comes into play. If ITS is promoted as a low-cost measure to achieve various objectives, it may undermine the ability of agencies to make a case for their preferred investments, which might be more capital intensive. However, agencies may also prefer ITS options precisely because of its lower cost. Therefore, our cases illustrated that we had to analyze the self-interests of agencies in order to determine their mutual interests, and ask what are the repercussions – positive and negative – of highlighting ITS as a low-cost improvement for both mobility and air quality (see Propositions 4 and 5).

While the context of Mexico City differs substantially from that of the US case study cities, the dynamics of these cases are similar. ITS deployments for air quality often reflect preferences for or against certain types of large-scale investments in new or expanded systems. For example, in Boston, the preference of the MBTA (the transit agency) is to avoid several transit projects that involve extending or restoring rail-based services. Therefore, there is greater consideration of ITS-based solutions for bus rapid transit type service, that could be considered an adequate substitute of Boston's transit commitments. In Houston, on the other hand, Metro (the transit agency) has been attempting to push a transit expansion program based on light rail. Therefore, they have highlighted the air quality benefits of light rail, while making little reference to the air quality benefits of improvements to bus services through ITS. Houston has also been supporting its case for continued investments in TranStar, the hub of ITS deployment in the region (including participation from the City of Houston, Harris County, Texas Department of Transportation and Metro). Therefore, the air quality benefits of TranStar and related ITS applications have been repeatedly stressed by the four agencies involved in TranStar. Los Angeles, has shifted transportation priorities radically, away from infrastructure expansion, to demand management and transit expansion. While there is a focus on the air quality benefits of applying ITS to transit, and to a more limited extent, to demand management (under their information-based transportation strategies category of TCMs), there seems to be a reluctance to highlight the potential air quality benefits of better managing traffic flow through enhanced operations on local streets and highways. These issues are discussed in depth in Chapter 6. However, it is important to highlight the similarities between these very different cities.

Therefore, we draw three important and interconnected conclusions from these cases. Again, these results are for the case of ITS and air quality in the US, and in Mexico City.

- The possibilities for achieving synergies (or “win-win” outcomes) must be defined, not according to the stated policy objectives or mission of the public sector agency, but according to the underlying interests and agendas of agencies, which may not align with the public interest.
"Cheap" solutions, such as ITS rather than conventional infrastructure, are not always in an agency's interests, as the agency defines them.

Low-cost innovations may compete with or support agency’s or elected official’s priorities for certain categories of investment.

On a different note, but also related to the issue of the cooperation, we found that a larger number of organizations (involved in the possible cooperation on ITS deployments for air quality purposes), did not necessarily lower the probability of successful IIDAPT, as was first hypothesized (see Proposition 6). There were indeed indications that a more limited number of actors involved in ITS deployment and air quality management could make cooperation easier, for example, Tulsa and Houston. However, when we turn to the case of Los Angeles, we find that a more decentralized institutional structure for transportation and air quality planning and management led to greater levels of “experimentation” with the use of ITS for air quality. This seems to have enabled a much greater range of IIDAPT, with many smaller agencies deploying different ITS technologies in support of air quality as well as mobility. Houston, on the other hand, with a more limited number of agencies, and more centralized transportation decisionmaking and highly coordinated ITS efforts through TranStar, may have limited the range of IIDAPT to only four application areas, which represent the core strengths of the TranStar organizations. Therefore, while the case studies did not provide conclusive results for the impact of a larger number of agencies, they did point to some interesting avenues for future research.

8.2.4.3 Role of Assessment and Adaptation in Public Sector Technology Deployments

We found a wide range of IIDAPT levels, which indicates a certain level of experimentation with new technologies. Yet, when looking at individual technologies/projects linking ITS to air quality benefits, we found that there was little active adaptation of technologies in response to information on their actual air quality impacts once deployed. Although assessments were relatively prevalent, they were typically ex ante evaluations intended to document anticipated benefits for showing eligibility for CMAQ funding, or justifying their inclusion in the list of TCMs in air quality plans. Assessment methodologies were not generally set up to provide new information. Therefore, we did not find many examples of adaptation and modification of ITS technologies in response to new information on air quality impacts (see Proposition 7). We highlighted two primary finding with respect to the role of assessment and adaptation in public sector technology deployments:

- New information on the impacts of new technologies does always not lead to adaptation.
- Assessments of technologies and their impacts are not well integrated into the technology deployment process, even where evaluations are required.

Returning again to the issue of mutual benefits for agencies, we find that the influence between new information and mutual benefits, as seen in Figure 8-1, may actually be in the opposite direction than what we hypothesized. We had originally anticipated that new information regarding the air quality benefits (or negative impacts), could change agencies perception of
mutual benefits, by either highlighting new opportunities, or identifying areas of conflict between mobility and air quality goals. However, agency interests and preferences were often immutable in the face of new information that emerged regarding the air quality impacts of ITS application. Information would generally be assimilated in ways that would further support their existing preferences. Therefore, another key finding is that:

- Mutual benefits tend to set priorities, and new information that can change the perception of those benefits is not always welcomed by agencies.

Indeed, even in the development of uniform protocols and guidebooks to assess the emission changes from ITS applications, we could clearly see existing organizational preferences reflected in how emission changes were calculated. Agencies in Houston, highly supportive of traffic flow improvements as a way to combat both congestion and air pollution, did not incorporate the impacts of induced demand into their calculations of traffic flow improvements. On the other hand, Los Angeles, more wary of the induced demand that could result from improvements to traffic flows and increased travel speeds, built those effects into their calculations. Even in Orlando, where air quality is not a pressing problem and does not currently constrain transportation investment decisions, information emerging from air quality studies of the impacts of electronic toll collection was used selectively. While the HC and CO reductions were highlighted by the agencies deploying electronic toll collection, the substantial NOx increases were essentially ignored.

8.2.5 Are ITS technologies being “shaped” to promote air quality objectives, and if so, how?

We now return to the question of the “shaping” of new technologies to ameliorate their negative impacts or generate additional benefits. Because we used a multiple case study approach, we were able to compare how ITS was used for air quality for cities on both the high and low ends of the IIDAPT scale. In addition, we could see the types of ITS applications that were being used for air quality purposes, as shown below.
Table 8-5  Frequency of use and average IIDAPT levels of each ITS application area

<table>
<thead>
<tr>
<th>ITS application areas</th>
<th>Frequency of use (0-5)</th>
<th>Average IIDAPT level (0-6)</th>
<th>Houston</th>
<th>Los Angeles</th>
<th>Boston</th>
<th>Orlando</th>
<th>Tulsa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arterial traffic flow improvements</td>
<td>4</td>
<td>3.9</td>
<td>4.5</td>
<td>5.5</td>
<td>2.5</td>
<td>–</td>
<td>2.5</td>
</tr>
<tr>
<td>Freeway management strategies</td>
<td>3</td>
<td>3.2</td>
<td>4</td>
<td>2.5</td>
<td>3</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Freeway traveler information</td>
<td>0</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Transit information</td>
<td>1</td>
<td>3</td>
<td>–</td>
<td>3</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Multi-modal information</td>
<td>1</td>
<td>4</td>
<td>–</td>
<td>4</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Transit operational improvements</td>
<td>2</td>
<td>3.3</td>
<td>–</td>
<td>2.5</td>
<td>4</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Transit fare payment systems</td>
<td>1</td>
<td>4.5</td>
<td>–</td>
<td>4.5</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Rideshare support</td>
<td>4</td>
<td>3.4</td>
<td>4</td>
<td>4.5</td>
<td>2</td>
<td>–</td>
<td>2</td>
</tr>
<tr>
<td>Demand management/pricing</td>
<td>2</td>
<td>4.8</td>
<td>5.5</td>
<td>4</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Other applications</td>
<td>1</td>
<td>4.5</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>4.5</td>
</tr>
</tbody>
</table>

Our analysis showed that for all metropolitan areas with even a minimal or anticipated air quality problem (i.e. all cities except Orlando), there were at least a few examples of the use of ITS to support air quality and mobility objectives. Again, in order to “qualify” as an example of IIDAPT, the technology analyzed had to support the dual objectives of mobility and air quality improvements. There are some ITS technologies, identified and discussed in Chapter 2, that have been developed for only air quality benefits, without an identifiable role in congestion mitigation or other mobility enhancement. These were not counted as IIDAPT, since we were focusing on the case of dual benefits for mobility and air quality.

In Table 8-5, we highlight the frequency of use of ITS technologies according to the ten application areas. Arterial traffic flow improvements – primarily through traffic signalization strategies – were found in four of the five cases. The use of internet ridematching services for carpool and vanpooling were also found in all cities except Orlando. We found that the provision of traveler information (freeway, transit, and multi-modal) was used infrequently for air quality purposes. This indicates that the vision of an “information-intensive transportation system” has not yet been realized, or that the air quality benefits of those technologies and services are not being exploited. Los Angeles was the exception in this respect. In fact, in their list of transportation control measures (TCMs) for their air quality management plan, the Metropolitan Planning Organization for the Los Angeles region (SCAG) has created a new category referred to as “Information-based Transportation Strategies,” which points toward this vision. In Chapter 6, we also looked at some of the “best practices” in the use of ITS for air quality in the five US case study cities analyzed in this research. These are summarized in Table 8-6.
### Table 8-6 IIDAPT “best practices” in ITS for air quality in five US cities

<table>
<thead>
<tr>
<th>IIDAPT</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ATSAC/ATCS in LA</strong></td>
<td>The Automated Traffic Surveillance and Control (ATSAC) system has undergone continual enhancements since the 1980s, allowing the addition of capabilities for traffic control, and more recently for transit signal priority. The Adaptive Traffic Control System (ATCS) is the latest software upgrade to ATSAC, developed in-house, with automated adjustment of signal timings in response to real-time traffic conditions. There is also cooperation with Metro’s for transit signal priority for the Blue Line light rail. The ATSAC system has received several awards for innovation, including an award from the US DOE’s 1995 National Awards Program for Energy Efficiency and Renewable Energy. Studies of air quality impacts have shown clear benefits, but to date there does not appear to be adaptation of the system specifically to air quality outcomes. Some proposals were made, but never fully implemented, to manage traffic in real-time using monitored CO levels and other emissions. Important expansions of the system (Wilmington, Harbor-Gateway) are funded with CMAQ. See trafficinfo.lacity.org/html/atsac_1.html.</td>
</tr>
<tr>
<td><strong>RCTSS in Houston</strong></td>
<td>Through cooperation between Metro and the City of Houston, signal hardware is being upgraded, also to include signal priority, as well as interconnected back to TranStar facility for centralized control and monitoring. The project is funded through CMAQ, and is included by the MPO as a TCM in Houston’s air quality plan.</td>
</tr>
<tr>
<td><strong>Universal fare system in LA</strong></td>
<td>CMAQ funding is supporting the multi-agency deployment of a universal fare payment system for transit. The project leader is Metro, but a number of transit agencies in LA county are involved in deployment to increase ridership through more seamless travel. This will cover nearly all major transit service operators of subway, light rail, bus and rapid transit in LA county.</td>
</tr>
<tr>
<td><strong>HOT lane in Houston</strong></td>
<td>This program is an extension of Houston’s HOV and ridesharing program. Through cooperation between Metro, TxDOT, and the Harris County Toll Authority, Houston implemented two of the country’s first managed lanes for carpools, vanpools, minivan pools, and buses. There is also cooperation from H-GAC through the management of the Commute Solutions program for ridematching. Only 2+ carpools (no SOVs) can access HOV lane for a toll. 3+ carpools access the lanes free. Extensive assessment has been done to maintain levels of service, but no evidence yet of adaptation to improve emissions outcomes.</td>
</tr>
<tr>
<td><strong>Ozone Alert! on VMS in Tulsa</strong></td>
<td>In anticipation of possibly exceeding the air quality standards in the early 1990s, Tulsa City/County Health, ODEQ, INCOG and ODOT organized an Ozone Alert! program. Agencies implement temporary measures to reduce emissions only on days predicted to have high pollution levels (which are infrequent). VMS are used to alert the public, and to encourage alternate modes of travel, off-peak travel, or telecommuting. This is a core part of Tulsa’s Clean Air Program. This program was recognized and highlighted by the EPA. See <a href="http://www.ozonealert.com">www.ozonealert.com</a>.</td>
</tr>
<tr>
<td><strong>Multi-modal information in LA</strong></td>
<td>The innovation in this system is the consolidation of information from a variety of motorized and non-motorized modes, presenting users with a unified and consistent interface (<a href="http://www.commutesmart.info">www.commutesmart.info</a>) for accessing traffic conditions, transit schedule and real-time information (where available), transit and bicycle trip planning, instant carpooling and other rideshare match information. Cooperation between LA, Orange, Riverside, San Bernardino and Ventura counties.</td>
</tr>
<tr>
<td><strong>Rideshare support in LA</strong></td>
<td>The database for Ridematch.info (also accessible via <a href="http://www.commutesmart.info">www.commutesmart.info</a>) in the LA region has more than a quarter of a million registered commuters. Web access information has been included as a TCM, and many rideshare activities have been funded through CMAQ. There has been innovation on the technical side with provision of real-time matching of carpools and online information on seat availability in existing vanpools. There has been cooperation for this program between the counties of LA, Orange, Riverside, San Bernardino and Ventura.</td>
</tr>
</tbody>
</table>
So, the “good news” was that federal regulations and funding programs in the US are spurring some innovation in the use of ITS for air quality purposes. As noted above, we saw examples of experimentation with ITS for ridesharing, public transit management and integration, and traffic flow improvements. However, the outcomes were strongly influenced by the mutual benefits – and mutual benefits between what are ultimately self-interested agencies not always reflecting “common good” of the public. In the five US case cities, and in Mexico City, we saw that mutual benefits from using ITS for air quality were defined in large part by the existing preferences for major transportation investments. Attempts to use ITS for air quality would generally be successful if it supported the preferred investments for both transit and roadway. They would be unsuccessful if it would undermine the ability of agencies to make the case for their preferred investments. Transportation agencies are taking advantage of the air quality benefits of ITS where it serves their interests, but it is not making them “greener.”

This research also highlighted that possibilities for longer term induced demand from ITS-based traffic flow improvements are generally ignored (or denied). As a result, we may not only be seeing some misuse of the CMAQ program funding, but also finding that cities are setting ITS on a so-called “technological trajectory” that is not particularly supportive of long-term air quality goals. By getting some overuse of ITS measures aimed at improving traffic flow and thus facilitating the use of the single occupancy automobile through supply side measures, we may be undermining or detracting from other efforts to focus ITS deployment on the demand side of transportation (through both pricing and supporting a broader range of viable alternatives to the private automobile), which could “shape” ITS technologies to be more compatible with long-term air quality goals. The use of ITS for support of ridesharing has been relatively widespread. However, there are indications that the concept of managed lanes – in which “underused” capacity on HOV lanes is utilized by tolling vehicles\(^{399}\) to use the lane – may begin to shift the emphasis away from better using limited capacity by actively promoting ridesharing, to better managing the use of limited capacity through pricing.

Taking into consideration what the experience in the US has been, in terms of using ITS to support air quality improvements, as well as what we have learned about the conditions that lead to lower or higher levels of IIDAPT, we now turn to the policy recommendations.

\(^{399}\) Either single occupancy vehicles or other vehicles with less than the required minimum for the HOV lane.
8.3 RECOMMENDATIONS

An important motivation of the development of the IIDAPT framework was to not only understand the conditions that lead to IIDAPT, but also to use those insights to develop recommendations for promoting higher levels of IIDAPT. We present this section in three parts. First, we provide policy recommendations for improving the general conditions for using ITS for air quality purposes. Second, we look at whether the current US system seems to be working in favor of high IIDAPT levels for ITS and air quality, or not. Finally, we review the recommendations for the case of Mexico City, both in terms of specific technologies, as well as improving the conditions for IIDAPT.

8.3.1 Improving the Conditions for Using ITS for Air Quality Purposes

We have answered the question of whether we can develop and test a framework for Integrated Innovation, Deployment and Adaptation of Public Technologies. We found that the IIDAPT framework—and in particular, the conditions of problem severity, mutual benefits and dedicated resources—could be used to predict IIDAPT levels. In addition to their predictive and explanatory role, we further propose that these conditions also have a prescriptive role, identifying possible policy interventions that could promote higher levels of IIDAPT. This points to our final research question:

Can we use this framework to provide policy recommendations for fostering higher levels of IIDAPT?

We have recognized that this has a normative component. It follows from the proposition that fostering technological innovations (such as ITS) that achieve multiple policy benefits (such as air quality improvements, congestion mitigation and improved transit) is desirable. On the other hand, what we do not suggest is that ITS is necessarily a better air quality measure than other mobile source emissions reductions measures. We are also not suggesting that air quality goals should trump mobility goals during the course of ITS deployments. What we do suggest is that “piggybacking” air quality benefits onto ITS deployments undertaken for mobility benefits, is a good idea.

We will propose four policy interventions for increasing IIDAPT levels for ITS and air quality. We emphasize that these policy interventions are based on a set of five case study cities in the US. Because these policy inventions are developed for the case of ITS and air quality, we caution readers against considering these policy interventions more broadly for technologies and issue areas not related to ITS and air quality (although we are hopeful that the IIDAPT framework can be useful in other contexts). We focused on three important conditions as predictors of IIDAPT: (1) problem severity, (2) mutual benefits, and (3) dedicated resources. We will discuss these as possible areas for policy intervention to increase levels of IIDAPT. We also identify policy interventions related to the condition of new information in the expectation (and hope) that by restructuring the manner in which information is generated and used, more innovation and adaptation can take place in order to maximize air quality benefits of ITS.
Policy Intervention 1: Increase the regulatory stringency for addressing air quality problems in metropolitan areas, to promote experimentation with ITS for supporting air quality goals.

Even if a problem itself is not at a crisis stage, regulatory pressure can provide the impetus to innovate. The severity of the problem will be defined according to the ability of the agencies to meet those regulatory requirements. Moreover, agencies will respond to current and anticipated problems. Therefore, more stringent legislation that clearly delineates the extent of the problem and the progress that needs to be made to bring conditions to an “acceptable” level, can lead to innovation.

Policy Intervention 2: Provide dedicated resources that create “slack” for innovation, in order to increase the likelihood of experimentation with ITS for air quality purposes.

Dedicated resources, such as CMAQ, can also be a source of support for innovations that cannot be funded easily from traditional funding sources. However, to truly be “slack,” they must be adequately protected from general budgetary pressures for other investments. For this reason, conditions upon their use and requirements for proving eligibility (documenting air quality benefits), are imperative.

Policy Intervention 3: Identify areas of mutual benefits – and areas of potential conflicts – with regards to the interests and agendas of key agencies, in order to foster cooperation on ITS innovations for air quality.

On the surface, mutual benefits between policy objectives of different agencies should be sufficient to garner support from multiple agencies. But, this does not provide a guarantee that agencies will be motivated to cooperate. While it is difficult to change the underlying interests of agencies, understanding these interests can help a policy entrepreneur develop a strategy for deploying ITS in ways that create real mutual benefits. By looking at various alternative technologies for mobility and air quality, a policy entrepreneur can determine whether it will undermine or support the ability of agencies to make the case for their other preferred investments. Another option is to attempt to change how agencies view the benefits of using ITS for air quality purposes. However, we found that in our case studies that new information regarding the air quality benefits or negative impacts of ITS did not tend to significantly shape actors’ perception of the “mutual benefits” to be gained.

Policy Intervention 4: Restructure assessments and dedicated resources into a more iterative process of experimentation and evaluation, in order to increase adaptation of ITS technologies to improve air quality outcomes.

The generation of new information could be better structured to provide for learning and adaptation. One approach would be to require more rigorous ex post analyses of emissions benefits, focusing on measurable outcomes. A portion of the dedicated funding categories could be set aside for analysis of emission and air quality outcomes, and verification of ex ante and ex post analyses of emissions benefits. This information could then be used to provide additional guidance on acceptable evaluation protocols for demonstrating eligibility for funding.
Verification of actual emissions benefits, and comparison with emissions benefits estimated in order to show funding eligibility, could be done on an audit-type basis, particularly for those technologies used most frequently, or those technologies with more uncertain benefits.

8.3.2 Current US Transportation and Air Quality Regulatory Framework

In Chapter 6, we also provided specific recommendations regarding the Congestion Mitigation and Air Quality (CMAQ) program and the regulatory framework of transportation conformity requirements in the US. Most of these recommendations, and critiques, related to the lack of adequate mechanisms for assessment and adaptation of ITS technologies to improve their performance in terms of air quality. There are still important unresolved assumptions and uncertainties behind the many of the ITS technologies that are deployed for purported air quality benefits. For example, perhaps the biggest weakness of the CMAQ program is that the required ex ante assessment provides very little room for learning – either agencies learning from their own deployments, or learning from the experiences of other agencies. Furthermore, there are no incentives or requirements to modify or adapt ITS deployments in the case that they are found to actually degrade air quality – for example, by increasing traffic speeds to the point where emission rates (grams/mile) are higher, or by inducing additional demand for travel in single occupancy vehicles by reducing travel times. While major infrastructure investments must be reviewed for conformity with air quality goals, there is no equivalent analysis for ITS deployments. Although the current levels of deployment of ITS, and the use of ITS to actively manage the transportation system, might not be advanced enough to see major impacts on air quality, with future improvements to the system, this may change. The debate over the environmental and air quality impacts of ITS, in the future, could be a repeat of the debate over the environmental and air quality impacts of highway expansion. Yet, the system is currently being set up to categorically exclude ITS from the same type of analysis to which, for example, a highway expansion or major interchange reconstruction, would be subjected. This practice should be reconsidered as ITS become more pervasive and used more intensively.

8.3.3 Technology and Policy Recommendations for Mexico City

In Chapter 7, we not only tested the IIDAPT framework for the case of Mexico City, but also used it to develop a set of recommendations for the use of ITS in support of air quality goals in Mexico City. Based upon the review of ITS technologies with possible air quality benefits in Chapters 2 and 3, as well as the review of the “best practices” in the use of ITS for air quality in the US in Chapter 6 (also shown in Table 8-6), we developed several specific technology recommendations for Mexico City. These technology recommendations took as a starting point the history of ITS deployment in Mexico City and the successes and challenges that agencies have had with these technologies. Our recommendations included the following:

- Build upon the experience in using ITS technologies for Metrobús – smart cards, AVL, bus operation center – to improve other existing government-operated public transit services. Also, use this service as a test bed for additional ITS-based improvements, such as conditional signal priority.
Consider the use of ITS for automated enforcement of lane use to enable an “open lane” busway for future extensions of the *Metrobús* where barrier-separated busways are infeasible.

For informal sector transportation, ITS applications such as smart cards and automation of the revenue collection process can support formalization and restructuring of the current *colectivo* operations into higher quality, better regulated and better integrated services.

Improvements to traffic flow through ITS have the potential to bring near-term emissions reductions by reducing idling and stop-and-go traffic conditions. Given the difficulties in providing a well-functioning fully adaptive signal control system, greater benefits may be gained from dedicating resources toward immediate signal optimizations, synchronization, and coordination, as well as interconnection of a larger share of signalized intersections back to the traffic control center, rather than spending the additional resources (monetary and personnel) needed to implement a fully adaptive system.

Reliable traveler information, particularly for incidents and events (ranging from sports events and concerts, to construction, to political marches and protests) could reduce the traffic and air quality impacts of these events. However, any future improvements to traveler information — particularly information provided via the web — should take a multi-modal approach which provides alternatives, rather than simply determining the best route and time to travel via automobile. An initial set of information for a multi-modal traveler information service should also include information, both static and real-time information where available, on all transit services, as well as information on bikeways.

In addition to the technology recommendations above, at the end of Chapter 7, we also identified several policy suggestions, following the same line of four policy interventions identified in Section 8.3.1. For example, one suggestion was the creation of a federal funding category for transportation projects with the potential for emission reductions, analogous to the Congestion Mitigation and Air Quality (CMAQ) program. However, it would need to be coupled to quantification and some reasonable level of “proof,” preferably through *ex post* analysis, of the air quality benefits achieved, perhaps with support of federal level agencies such as INE.

Another option could be to create an institution that had an interest in identifying and promoting ITS as a tool to better manage the transportation system and its impacts. One option would include incorporating the functions of the Metropolitan Transportation Commission (*Cometravi*) into the Metropolitan Environmental Commission (*CAM*), which has historically been a much stronger actor for metropolitan-level coordination. This would combine the mobility objectives of *Cometravi* with the environmental and air quality objectives of *CAM*. However, we also warned that by continuing to sideline the role of transportation agencies responsible for operations and ITS, it will be difficult to innovate and experiment with ITS in a way that improves air quality outcomes.
8.4 FUTURE RESEARCH

In this section, we describe possible areas for future research, based upon the IIDAPT framework and the research methodology used in this thesis. First, we discuss possible refinements to the IIDAPT framework, as applied to ITS and air quality, through additional testing based on the case study approach. Other possible extensions of the analysis include a macro-level analysis using surveys of larger sample of metropolitan areas, as well as a micro-level analysis focusing on a sample of individual technology deployments. We then look beyond the basis for this analysis, which was the deployment of ITS for air quality objectives in US metropolitan areas and the case of Mexico City, and consider possible extensions to additional countries and cities, as well as opening up the analysis to consider the applicability of the IIDAPT framework to other technologies and issues areas beyond ITS for mobility and air quality.

8.4.1 Refinement of the IIDAPT Framework and Methodology in the Context of ITS

8.4.1.1 Further Validating the IIDAPT Framework

In testing the IIDAPT framework, we found that the conditions of problem severity, mutual benefits and dedicated resources were the best predictors of IIDAPT levels. However, we also found interesting interactions between mutual benefits and dedicated resources, as well as between mutual benefits and cost. We also found that the problem severity, as perceived by the local agencies, was more subtle than a simple non-attainment or attainment designation for ambient air quality standards. Therefore, in order to further refine the IIDAPT framework, we could retest the framework on additional cities, using a modified version of Figure 8-1. Cities could be chosen according to variations in these three conditions: problem severity, mutual benefits and dedicated resources, for example, looking at cities with more severe air quality problems, but lower levels of CMAQ funding. While we tested the framework for cities across the range of air quality problems — Tulsa and Orlando on the low end, Houston and Los Angeles on the more severe end — it could be illustrative to look more closely at cities with moderate or marginal air quality problems, to see if and how they are balancing air quality and mobility objectives through the use of ITS.

In Section 8.2.2.3, we also pointed to further validation of the IIDAPT framework through a comparison of predicted and actual IIDAPT levels for more disaggregated measures, focusing on variations in average IIDAPT level, range, and intensity.

8.4.1.2 Survey of ITS Applications Used for Air Quality

Our research methodology was designed to identify the greatest scope of possible IIDAPT. We reviewed candidate IIDAPTs from a range of project types: CMAQ projects, TCMs, emission reduction measures in other program/planning documents (such as an Early Action Compact), or measures as part of other clean air programs. We could have gained uniformity by using only CMAQ projects, or only official TCMs, although at the expense of overlooking possible cases of IIDAPT for ITS and air quality, particularly in cities that were in attainment with air quality standards.
The first step toward the identification of examples of IIDAPT was through the interview process and site visits. Interviewees were asked to identify technologies with an air quality benefit, including technologies funded through the Congestion Mitigation and Air Quality (CMAQ) program and included in air quality management plans (specifically, State Implementation Plans, or SIPs for non-attainment areas), or other technologies whose air quality impacts had been evaluated. The second step was to review air quality and transportation plans and programs for CMAQ-funded ITS, ITS included as a TCM, or ITS otherwise included as part of an air quality management plan. This research highlighted which agencies undertake these projects, how they are funded, and how they are included in transportation plans and programs. Building on this knowledge, another area for future research would be to develop targeted questionnaires regarding the use of ITS technologies for air quality purposes. These questionnaires could be customized to the type of agency (transportation, air quality, MPO) and level of government (city, county, state), as well as the air quality status of the metropolitan area (attainment, non-attainment).

8.4.1.3 Improved quantification of IIDAPT levels

As discussed above, we developed a quantitative scale for IIDAPT levels, in which we gave an IIDAPT “score” to individual technology deployments. This allowed for additional rigor in the comparison of IIDAPT levels, between different technologies, and across five metropolitan areas. The question is, how well did this scale work in practice? We found cooperation and innovation were easier to categorize, and sufficient information could generally be gleaned from transportation and air quality planning and programming documents. However, it was substantially more difficult to gather information on assessments and adaptation. Information on assessments would generally require access to internal evaluations or evaluations carried out by consultants that are often not available. Therefore, the potential outcome is that the unavailability of information on assessments is counted as “no assessment,” on our scale, therefore bringing down the IIDAPT score for that particular technology. Adaptation is more difficult to determine, since it requires an in-depth knowledge of the evolution of each project’s design and implementation, and linking any changes in design or operational characteristics to assessments and evaluations. However, this occurs for all cities, meaning that it should not drastically change a city’s level of IIDAPT relative to other cities (as shown, for example, in Figure 8-3). Therefore, while one possible area for future research is to broaden the analysis through a survey-based approach, another possibility is to complement this with several more in-depth case studies of individual technology deployments, that would focus on innovation, cooperation, assessment and adaptation. By tracing the history of a few specific ITS deployments, one could capture the evolution of those technologies, and the conditions that influenced IIDAPT levels. It could also be used to gain a better understanding of the role of assessment and adaptation, by following how information on air quality impacts was both generated and used (or ignored).

8.4.1.4 IIDAPT for ITS and Security and Disaster Response

Finally, another area for further validation of the IIDAPT framework for ITS, would be to examine the emerging use of ITS applications to also provide benefits for homeland security
and/or disaster response. In the post-September 11th era, pressures for improved security of
transportation facilities, ranging from bridges to buses and subways, have led many promoters of
ITS technologies to highlight their dual uses. Technologies for surveillance, communication,
and response, are critical for detecting and responding to possible security threats to
transportation infrastructure. They can also support disaster response, whether for manmade
(terrorist attacks) or natural (hurricanes, earthquakes) disasters (Pinelis 2006). The use of ITS
for the multiple policy objectives of mobility and homeland security or disaster response, would
be an interesting contrast to the case of ITS for mobility and air quality. Because homeland
security issues might be a more central motivation for the adoption and deployment of ICT
technologies for transportation infrastructure, it could mean that homeland security benefits
would not have to “piggyback” on mobility gains in the same manner as air quality benefits.

8.4.2 Application of IIDAPT Framework to Other Countries/Cities

In Chapter 7, we applied the IIDAPT framework to the case of Mexico City. We found that it
also performed well in this context, and was able to predict IIDAPT levels, although they could
not be quantified in the precisely the same manner as in the US. We also had to measure the
seven conditions for Mexico City somewhat differently, taking into account the institutional
structures and processes for transportation and air quality planning and management in Mexico
City.

Having found that the framework could indeed be applied outside of the US, we suggest two
further avenues of research. First, would be to apply the framework to countries and cities with a
longer history of ITS deployment, principally, Europe and Japan, where ITS programs have been
under development since approximately the same time as in the US. This would enable us to test
the validity of the IIDAPT framework again for the case of ITS and air quality. It could also
point to additional conditions that can lead to higher or lower levels IIDAPT, which could be
used to provide policy recommendations for the US, and vice versa. This would also have a
practical purpose. Given the national differences in ITS technologies that are currently deployed
and under deployment, there could be important lessons to be learned about the air quality
impacts of different ITS technologies, and the ways in which ITS can be deployed to improve air
quality outcomes. In Chapter 2, we identified ITS-supported applications such as congestion
pricing in London, and emissions-based speed control in the Netherlands. The lessons learned
from these deployments, in terms of the conditions that enabled their success, could be brought
back to the US, Mexico and elsewhere.

The second avenue of research would be to apply the IIDAPT framework to additional
megacities in the developing world, and begin to build a base for cross comparison between
cities deploying ITS in ways that either benefit or worsen air quality. For example, there has
been a trend of Latin American cities following the trends set by other Latin American cities, as
witnessed by the wave of Bus Rapid Transit systems have been initiated following the early
example of Curitiba, Brazil, and more recent example of Bogotá, Colombia. Furthermore, cities
such as Santiago, Chile, São Paulo and Rio de Janeiro, Brazil, Bogotá, Colombia, and Mexico
City are facing similar challenges in transportation and air quality. Again, there could be cross-
fertilization both in terms of information on the ITS technologies themselves – what works well
and what does not work well for air quality and mobility management – as well as the conditions that are necessary to make this type of innovation possible.

Looking beyond Latin America, there a number of megacities in developing countries, particularly in China and India, that are seeing major transformations in their transportation systems and mobility trends. Beijing would be a particularly interesting example to follow closely. As they prepare for the 2008 Olympic Games, they face the dual challenges of improving mobility in a city where automobile ownership is growing dramatically, and reducing the extremely high levels of air pollution for which the Chinese megacities are rapidly becoming notorious. Furthermore, hosting the Olympic Games has often been an important spur to cities to improve their traffic management capabilities and deploy advanced systems such as ITS. As discussed in Chapter 2, there have already been plans for complex systems of bans on gross polluting vehicles during high pollution episodes, with real-time provision of additional bus services to compensate drivers not allowed to enter the city because of the vehicle ban, as well as other traffic and transit management strategies to bring pollution levels down during these episodes. Therefore, their success in using ITS for air quality management in real-time should be watched closely.

8.4.3 Application of IIDAPT Framework to Other Public Technologies

Looking beyond ITS and air quality, the issues identified in the IIDAPT framework point to broader questions of how to appropriately manage technology and its impacts on society, particularly technologies deployed by the public sector. Although we chose the case of ITS and air quality in order to test and refine this new framework, it was developed with the intention of being applicable to a wide range of technologies and issues. Therefore, we argue that a priority for future work is to apply and test the validity and usefulness of this framework to other public technologies.

A logical extension would be to consider additional areas in which environment impacts are co-produced through the deployment of new technologies and systems by the public sector. For example, one of the earlier winners of the Innovations in Government award from the Ford Foundation/Harvard University Kennedy School of Government was Arcata, California. Their innovation in wastewater management had the core policy objective of managing sewage. However, through a multi-stage process of sedimentation tanks, oxidation ponds, and artificial marshes, the "non-smelling" marshes have also provided benefits as a destination for recreation, hiking, bicycling, and fishing, and serve as an important wildlife refuge. Other examples could be envisioned for solid waste management, and other areas of environmental and energy management.

This thesis examined the implications of the application of information and communications technologies (ICT) to the management of transportation systems. However, ICT is increasingly pervasive in other governmental activities. Another interesting example is the case of municipal electric utilities (MEUs), which through the deployment of fiber optic, have also become broadband providers. Therefore, in addition to better control of their own electric utility network, these MEUs may also be creating additional public benefits, such as economic
development spillovers to local communities through the provision of broadband service (Osorio 2006). Other examples include geographic information systems, smart cards, radio-frequency identification devices (RFID), information kiosks, and online transactions for government services from employment applications to payments of fines and fees. Returning again to ITS, there have also been efforts to leverage ITS infrastructure, such as camera surveillance and communications links, to provide not only benefits for transportation management and mobility, but for crime prevention and response.

While ICT seems to be the emerging technology which is expanding most rapidly in usage by government agencies, in the future, other emerging technologies, such as biometrics (digital fingerprinting, iris scans, and face recognition) may be the next cutting edge. Identifying pathways and creating the conditions for public sector agencies to use technologies in ways that create additional benefits, or reduce negative impacts, are critical. We suggest that this research takes an important step in that direction.

Yet, looking beyond the technology component, this work is about the generation of mutual benefits on several policy dimensions. We considered the case of mobility and air quality—two policy objectives that are often presented as trade-offs—and identified the possibilities for co-producing better mobility and air quality by identifying the possible synergies offered by new technologies. This requires cooperation, and some foresight, by the multiple agencies involved. It also reveals the challenges of achieving what may be mutual benefits from the viewpoint of the public, but not necessarily from the viewpoint of the agencies involved. But, it also highlighted cases where this can and has been done, and the conditions which facilitated these outcomes.
8.5 FINAL THOUGHTS

There is no simple answer to the question which provided the initial spark for this research: are Intelligent Transportation Systems beneficial or detrimental for air quality? The conclusion of “it depends” might be unsatisfactory to those who wish to have closure on this question. Yet, we found that this indeterminate conclusion opened up a new line of questioning and reasoning – one that led us to consider the broader, and more fundamental issues of how societies manage emerging technologies and their impacts. We began this thesis with a discussion of the different visions that emerged in the mid-1990s regarding ITS, air quality, and sustainable communities. We emphasized that it is important to keep that broader debate open, and not allow for early closure on the issue of ITS and environmental impacts. Having presented the cases and the analysis, we reiterate that appeal to continue the debate. By failing to recognize and study the ways in which societies shape technological systems, such as ITS, in ways that also support environmental quality, we will continue to develop environmentally unsustainable systems.

We are interested in the “social shaping” of ITS technologies, and the social shaping of their impacts on air quality. We looked in great depth at the issue of if, how, why and under what conditions the public agencies deploying these technologies are actually using ITS for air quality purposes. There are a number of obstacles to the adoption and use of ITS in more environmentally sustainable ways. Yet, we also found examples of agencies, in nearly all of our case studies, applying ITS in ways that would contribute to air quality as well as to mobility. Our hope is that the efforts to co-produce environmental benefits along with mobility will also grow, as ITS becomes more pervasive and is used more intensively to manage transportation systems and provide new mobility options. This thesis provides reasons for optimism that this vision can be achieved, and, we hope, points to the way forward to do so.

***
REFERENCES


Houston-Galveston Area Council (2005). Conformity Determination for the 2025 Regional Transportation Plan and the 2006-2008 Transportation Improvement Program for the Houston-Galveston Transportation Management Area. Houston, TX.


Texas Commission on Environmental Quality (2004). Revisions to the State Implementation Plan for the Control of Ozone Air Pollution, Houston/Galveston/Brazoria Ozone Nonattainment Area. Austin, TX.

Texas Commission on Environmental Quality (2004). Texas 2002 Periodic Emissions Inventory. Austin, TX.


Texas Transportation Institute (2003). The Texas Guide to Accepted Mobile Source Emission Reduction Strategies, Prepared in cooperation with the Texas Department of Transportation and in association with the Environmental Protection Agency, Federal Highway Administration, Federal Transit Administration, and Texas Commission on Environmental Quality: 321 pages.


(IUAPPA) and Integrated Program on Urban, Regional and Global Air Pollution (IPURGAP) Joint Seminar.


SELECTED WEBSITES

GENERAL
Joint Program Office of the Department of Transportation: www.its.dot.gov
Benefits and costs database: www.itsbenefits.its.dot.gov
ITS Deployment Tracking: www.itsdeployment.its.dot.gov
Environmental Protection Agency: www.epa.gov
Texas Transportation Institute Urban Mobility Report: mobility.tamu.edu/ums
ITS America: www.itsa.org

U.S. CASE STUDY CITIES

Houston
Houston-Galveston Area Council: www.h-gac.com
TranStar: www.houstontranstar.org
Commute Solutions: www.vanpool.org
Texas Department of Transportation: www.dot.state.tx.us
Texas Commission on Environmental Quality: www.tceq.state.tx.us
Galveston-Houston Association for Smog Prevention: www.ghasp.org

Los Angeles
California Air Resources Board: www.arb.ca.gov
California Department of Transportation (Caltrans): www.caltrans.ca.gov
Southern California Association of Governments: www.scag.ca.gov
Los Angeles City Department of Transportation: trafficinfo.lacity.org
Los Angeles County Metropolitan Transportation Authority: www.mta.net
Commute Smart Program: www.commutesmart.info

Boston
Massachusetts Turnpike Authority www.masspike.com
Massachusetts Highway Department: www.mhd.state.ma.us
Executive Office of Transportation: www.eot.state.ma.us
Boston MPO/Central Transportation Planning Staff: www.bostonmpo.org
Massachusetts Bay Transportation Authority: www.mbta.com
Orlando
Florida Department of Transportation: www.dot.state.fl.us
Metroplan Orlando: www.metroplanorlando.com
Orlando Orange County Expressway Authority: www.expresswayauthority.com
Florida Department of Environmental Protection: www.dep.state.fl.us

Tulsa
Oklahoma Department of Transportation: www.okladot.state.ok.us
Oklahoma Commission on Environmental Quality: www.deq.state.ok.us
Tulsa Ozone Alert program: www.ozonealert.com

MEXICO CITY
Government of the Federal District: www.df.gob.mx
National Institute of Ecology: www.ine.gob.mx
As discussed in Chapter 2, emission factors can also be affected significantly by acceleration rates. These three graphs show how emissions rates (grams/second) increase with increased accelerations (between 0 and 10 mph/sec) and decelerations (between 0 and -10 mph/sec). As can be seen, decelerations have very low emission rates, while "hard" accelerations (particularly above 3 mph/sec) can augment emissions rates greatly. This effect is particularly true for acceleration events at higher speeds.

Figure A-1  HC emissions factors by acceleration at 10, 35, 60 mph (from CMEM)
Figure A-2  CO emissions factors by acceleration at 10, 35, 60 mph (from CMEM)

Source: Data from (Dowling, Ireson et al. 2005, Tables 47-49)

Note that although Tables 47-49 express the emissions factors in grams per hour, the actual measure is grams per second (see page 143, Section 16.3).
Figure B-2  Intelligent Infrastructure (continued)
C.1 **WHAT IS TRANSPORTATION CONFORMITY?**

In essence, the CAAA defined transportation conformity as meaning that all transportation plans, programs and projects funded or approved by the FHWA or FTA must conform to the *purpose* of a state's air quality implementation plan to reduce the severity and number of violations of the federally-mandated air quality standards. Conformity determinations are made jointly by the FHWA and FTA, and are required for all areas out of attainment (or previously out of attainment, and in "maintenance") for the NAAQS for ozone, carbon monoxide, fine and coarse particulate matter, or nitrogen dioxide. When developing the State Implementation Plan (SIP), metropolitan areas must show that the mobile source emissions are within the allowed "motor vehicle emissions budget" that will be necessary to bring criteria pollutant concentrations within the NAAQS by the timeframe established by the CAAA of 1990.

When a deadline is passed for a conformity determination, there is a what is called a "conformity lapse," meaning the use of federal transportation funds is restricted. Until a conformity determination can be made, federal funding is restricted for all projects except approved TCMs, safety projects, and projects that have already been authorized by the FHWA/FTA.

The concept of Transportation Control Measures (TCM) was not a new addition. However, TCMs were given renewed emphasis and special status with the CAAA of 1990. The Federal Highway Administration gives the following guidance regarding TCMs.

"Under the Transportation Conformity Rule, Transportation Control Measures (TCMs) are strategies that: (1) are specifically identified and committed to in State Implementation Plans (SIPs); and (2) are either listed in Section 108 of the Clean Air Act (CAA), or will reduce transportation-related emissions by reducing vehicle use or improving traffic flow. Measures which reduce emissions by improving vehicle technologies, fuels, or maintenance practices are not TCMs.

Section 108 of the CAA provides examples of transportation control measures including, but not limited to: improved public transit, traffic flow improvements and high-occupancy vehicle lanes, shared-ride services, bicycle/pedestrian facilities, and flexible work schedules.

Timely implementation of TCMs criterion must be satisfied before conformity determinations can be made. Additionally, any changes to TCMs must go through the SIP process. Consequently, TCMs receive the highest priority for funding under the Congestion Mitigation and Air Quality Improvement (CMAQ) Program.

Many other measures, similar to the TCMs listed in the CAA, are being used throughout the country to manage traffic congestion on streets and highways and to reduce vehicle emissions. Increasingly they are being recognized for their benefits toward improving an area's livability. These TCM type activities may be eligible for CMAQ funding, whether
or not they are in approved SIPs, if they are documented to have emission reduction benefits in nonattainment and maintenance areas. These activities have been employed throughout the country for many years and include many travel demand management and transportation system management applications.”


Because we discuss the linkages between ITS and Transportation Control Measures, we provide the following tables that highlight the TCMs that can be either ITS, or ITS enhanced in Section C.2 below. This builds off of the lists of TCMs provided by Eisinger et al, which describes where possible TCMs are described in the regulations and regulatory guidance (Eisinger and Niemeier 2004).
### C.2 ITS-RELATED TRANSPORTATION CONTROL MEASURES

Table C-1 Traffic Flow Improvements, Demand Management and Telecommuting

<table>
<thead>
<tr>
<th>Traffic Flow Improvements</th>
<th>Role of ITS</th>
<th>Section 108(a)</th>
<th>CMAQ</th>
<th>SIP Guidance</th>
<th>EPA RACM</th>
<th>Serious/Severe OD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traffic signalization</td>
<td>●</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Freeway/incident management</td>
<td>●</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HOV Facilities</td>
<td>○</td>
<td>X</td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Traveler information</td>
<td>●</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Turn lanes and other intersection improvements</td>
<td>●</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bus traffic signal preemption</td>
<td>●</td>
<td>X</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Other traffic flow improvements</td>
<td>○</td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Traffic condition/announcement signs</td>
<td>●</td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>One-way streets</td>
<td>●</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ramp metering</td>
<td>●</td>
<td>X</td>
<td></td>
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</tr>
<tr>
<td>Motorist aid services</td>
<td>○</td>
<td>X</td>
<td></td>
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<tr>
<td>Ridesharing</td>
<td>●</td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Regional rideshares</td>
<td>○</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Vanpool programs</td>
<td>○</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Park-and-ride lots</td>
<td>○</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Ride matching</td>
<td>○</td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Transportation management associations</td>
<td>●</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>School car pools</td>
<td>○</td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Public information</td>
<td>○</td>
<td>X</td>
<td></td>
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</tr>
</tbody>
</table>

**Travel Demand Management**

| Regional TDM                                   | ○           | X              |      |              |          |                   |
| Employer trip reduction programs               | ○           | X              | X    | X            | X        | X                 |
| Guaranteed ride home                           | ○           | X              |      |              | X        |                   |
| Improved airport access                        | ●           | X              |      |              |          |                   |
| Ozone action day programs                      | ○           | X              |      |              | X        |                   |
| Proximate commute programs                     | ○           |                |      |              | X        |                   |
| Flex time                                      | X           | X              |      |              |          |                   |
| Compressed work week                           | X           |                |      |              |          |                   |
| Trip reduction ordinances                      | X           |                |      |              |          |                   |
| Vehicle use restrictions by geographic area of peak use periods | ○      | X              |      |              | X        |                   |
| No-drive days                                  | ○           |                |      |              | X        |                   |
| In-house transportation coordinator            | ●           |                |      |              |          |                   |

**Tele-work (Telecommute)**

| Satellite work centers                        | ●           | X              | X    | X            | X        |                   |

*Although based on information and communications technologies, we do not include telecommuting under our definition of ITS, which is the application of these technologies to the surface transportation systems. Telecommuting is the substitution of physical travel by electronic communication.*
### Table C-2 Biking/Walking, Transit and Paratransit

#### Identification of TCMs

<table>
<thead>
<tr>
<th>Role of ITS</th>
<th>Section 108/20</th>
<th>CMAQ</th>
<th>SIP Guidance</th>
<th>EPA RACM</th>
<th>SRRA: State Rule Approval</th>
</tr>
</thead>
</table>

#### Bicycle/Pedestrian Oriented Programs

<table>
<thead>
<tr>
<th>Program</th>
<th>Section 108/20</th>
<th>CMAQ</th>
<th>SIP Guidance</th>
<th>EPA RACM</th>
<th>SRRA: State Rule Approval</th>
</tr>
</thead>
<tbody>
<tr>
<td>Designated lanes/routes</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Safety enhancements</td>
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<tr>
<td>Transit support facilities</td>
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<tr>
<td>Secure bicycle storage</td>
<td></td>
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<tr>
<td>Education programs</td>
<td></td>
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<tr>
<td>Shower/locker facilities</td>
<td></td>
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<tr>
<td>Widening sidewalks</td>
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<tr>
<td>Pedestrian grade separation</td>
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<tr>
<td>Pedestrian control barriers</td>
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<tr>
<td>Pedestrian malls</td>
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</tbody>
</table>

#### Transit Improvements

<table>
<thead>
<tr>
<th>Program</th>
<th>Section 108/20</th>
<th>CMAQ</th>
<th>SIP Guidance</th>
<th>EPA RACM</th>
<th>SRRA: State Rule Approval</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shuttle, feeders, paratransit, multimodal transfer centers</td>
<td></td>
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<tr>
<td>New capital systems/vehicles</td>
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<tr>
<td>Conventional service upgrades</td>
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<tr>
<td>Park-and-ride lots</td>
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<tr>
<td>Station cars</td>
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<tr>
<td>Station and bus stop improvements</td>
<td></td>
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<tr>
<td>Transit service expansions</td>
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<tr>
<td>Express bus</td>
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<tr>
<td>Shuttle circulators</td>
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<tr>
<td>Coordinated fare</td>
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<tr>
<td>Fare reductions</td>
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<tr>
<td>Guided busways</td>
<td></td>
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<tr>
<td>Exclusive bus and HOV lanes/streets/freeway bypasses</td>
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<tr>
<td>Contra-flow bus and HOV lanes</td>
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<tr>
<td>Heavy transit rail</td>
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<tr>
<td>Light rail transit</td>
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<tr>
<td>On-site transit pass sales</td>
<td></td>
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<tr>
<td>Marketing</td>
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<tr>
<td>Operations monitoring and improvements</td>
<td></td>
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<tr>
<td>Transfer improvements</td>
<td></td>
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<tr>
<td>Elderly and youth fares</td>
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<tr>
<td>Commuter discounts</td>
<td></td>
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<tr>
<td>Simplified fare collection</td>
<td></td>
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</tbody>
</table>

#### Improved Paratransit

<table>
<thead>
<tr>
<th>Program</th>
<th>Section 108/20</th>
<th>CMAQ</th>
<th>SIP Guidance</th>
<th>EPA RACM</th>
<th>SRRA: State Rule Approval</th>
</tr>
</thead>
<tbody>
<tr>
<td>Taxi/group riding programs</td>
<td></td>
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<tr>
<td>Dial-a-ride</td>
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<tr>
<td>Jitney service</td>
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<tr>
<td>Taxi deregulation</td>
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<tr>
<td>Marketing</td>
<td></td>
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</tbody>
</table>

- **●** ITS application
- **○** ITS enabled/enhanced

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Table C-3 Pricing, Parking, Smart Growth and Other Measures

<table>
<thead>
<tr>
<th>Identification of TCMs</th>
<th>Role of ITS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Section 108/6</td>
</tr>
<tr>
<td>Subsidies and discounts</td>
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<tr>
<td>Charges and fees</td>
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<tr>
<td>Parking cash-out</td>
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<tr>
<td>Transit checks</td>
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</tr>
<tr>
<td>Congestion pricing</td>
<td></td>
</tr>
<tr>
<td>HOV toll reductions</td>
<td></td>
</tr>
<tr>
<td>Tax incentives for transit</td>
<td></td>
</tr>
<tr>
<td>Peak hour tolls</td>
<td></td>
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<tr>
<td>Low-occupancy vehicle tolls</td>
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</tr>
<tr>
<td>Gasoline tax</td>
<td></td>
</tr>
<tr>
<td>Peak/off-peak transit fares</td>
<td></td>
</tr>
<tr>
<td>Elderly and handicapped fares</td>
<td></td>
</tr>
<tr>
<td>Employer-subsidized pooling programs</td>
<td></td>
</tr>
<tr>
<td>Parking rate changes/taxes</td>
<td></td>
</tr>
<tr>
<td>Vehicle taxes</td>
<td></td>
</tr>
<tr>
<td>Parking management</td>
<td>✔</td>
</tr>
<tr>
<td>Preferential parking for HOV</td>
<td></td>
</tr>
<tr>
<td>Parking pricing</td>
<td></td>
</tr>
<tr>
<td>Zoning requirements</td>
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</tr>
<tr>
<td>Commercial vehicle management</td>
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</tr>
<tr>
<td>On-street parking restrictions</td>
<td></td>
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<tr>
<td>Residential parking control</td>
<td></td>
</tr>
<tr>
<td>Off-street parking restrictions</td>
<td></td>
</tr>
<tr>
<td>Parking rate changes</td>
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</tr>
<tr>
<td>Bus stop relocation</td>
<td></td>
</tr>
<tr>
<td>Loading zone restrictions</td>
<td></td>
</tr>
<tr>
<td>Sidewalk widening (safety buffer)</td>
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</tr>
<tr>
<td>Parking duration restrictions</td>
<td></td>
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<tr>
<td>Improved enforcement efforts</td>
<td></td>
</tr>
<tr>
<td>Elimination of parking subsidies</td>
<td></td>
</tr>
<tr>
<td>Smart Growth</td>
<td>✔</td>
</tr>
<tr>
<td>Infill Development</td>
<td></td>
</tr>
<tr>
<td>Transit Oriented Development</td>
<td></td>
</tr>
<tr>
<td>Mixed-use development</td>
<td></td>
</tr>
<tr>
<td>Location efficient mortgages (near transit)</td>
<td></td>
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<tr>
<td>Programs to facilitate non-auto travel to special activity centers</td>
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</tr>
<tr>
<td>Extended Idling Controls</td>
<td>✔</td>
</tr>
<tr>
<td>Reduce truck idling</td>
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</tr>
<tr>
<td>Commercial Vehicle Control</td>
<td></td>
</tr>
<tr>
<td>On-street loading restrictions</td>
<td></td>
</tr>
<tr>
<td>Off-street loading areas</td>
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<tr>
<td>Peak-hour on-street loading prohibition</td>
<td></td>
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<tr>
<td>Truck route system</td>
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<tr>
<td>Peak-hour truck restrictions</td>
<td></td>
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<tr>
<td>Voluntary removal of pre-1980 light duty vehicles and trucks</td>
<td></td>
</tr>
</tbody>
</table>

* ITS application
  ○ ITS enabled/enhanced

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C.3 WHAT IS THE CONGESTION MITIGATION AND AIR QUALITY (CMAQ) IMPROVEMENT PROGRAM?

ISTEA provided the Congestion Mitigation and Air Quality Improvement Program (CMAQ) funds to carry out transportation related programs to meet conformity requirements. Therefore, CMAQ has been called “the funding arm of the Clean Air Act” (Federal Highway Administration 2002). The CMAQ program created a funding source for transportation projects designed to “contribute to the attainment [or maintenance] of a national ambient air quality standard” (23 USC 149).\(^{401}\) The creation of the CMAQ program has been described as “an innovative and important tool designed to reduce pollution from the transportation sector by funding innovative projects and programs to reduce emissions” (Government Printing Office 2004). Because CMAQ was intended to fund projects like Transportation Control Measures, there is substantial overlap, and many of the issues in attempting to determine the role of ITS in TCMs, apply in a similar manner to the CMAQ program.\(^{402}\)

**Figure C-1 CMAQ Reporting Categories**

<table>
<thead>
<tr>
<th>(a) public-private partnerships;(^ {403})</th>
</tr>
</thead>
<tbody>
<tr>
<td>(b) experimental pilot projects:</td>
</tr>
<tr>
<td>(c) transit: facilities, vehicles and equipment, <em>operating assistance for new transit service</em>, etc;</td>
</tr>
<tr>
<td>(d) shared-ride: vanpool and carpool programs and parking for shared-ride services, etc;</td>
</tr>
<tr>
<td>(e) traffic flow improvements: traffic management and control services, signalization projects, ITS projects, intersection improvements, and <em>construction or dedication of HOV lanes</em>, etc;</td>
</tr>
<tr>
<td>(f) demand management: trip reduction programs, transportation management plans, flexible work schedule programs, vehicle restriction programs, etc.;</td>
</tr>
<tr>
<td>(g) pedestrian/bicycle: bikeways, storage facilities, promotional activities, etc; and</td>
</tr>
<tr>
<td>(h) I/M and other TCMs (not covered by the above categories).</td>
</tr>
</tbody>
</table>

*Source: (Federal Highway Administration 1994; Federal Highway Administration 1999)*

There are signs of an increased use of ITS in the CMAQ Program. After five years of the programs operations, in FY1997 “the majority of CMAQ funds went to traffic flow improvements for the first time in program history, and much of this growth can be attributed to increased interest in ITS activities” (Federal Highway Administration 2002).

With CMAQ, program goals were established at the federal level, but local areas, through metropolitan planning organizations (MPOs), would have the responsibility for “project selection

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\(^{401}\) TEA-21 expanded the CMAQ program to include maintenance areas in the funding apportionment.

\(^{402}\) It should be noted that vehicle scrappage programs are explicitly excluded from CMAQ funding.

\(^{403}\) Italics indicate those projects included for the first time in TEA-21.
and implementation” (Transportation Research Board 2002) p 21. Michael Savonis, who was the CMAQ program manager during its early years and developed the policy and eligibility criteria for CMAQ referred to it as “The $6 Billion Experiment” in the spending of federal transportation dollars (Savonis 1995). According to Savonis, CMAQ was emblematic of the more decentralized, local, intermodal and flexible approach to transportation decision making that characterized ISTEA.

The term “experiment” used by Savonis in 1995, was echoed in the report of the NAS’ review of the program in 2000. The report notes that the funding enables areas to “experiment with nontraditional projects,” “think seriously about new strategies,” and also “encourages interagency consultation and cooperation” (Transportation Research Board 2002. p8). CMAQ encouraged innovation by assuming some of the financial and political risk of innovative strategies, as the funds explicitly prohibits the use of funds to provide new capacity for single occupancy vehicles, and therefore agencies were not concerned about using up scarce highway or transit funds for the ITS, demand management, pedestrian and bicycle, shared ride, and other projects that were funded under CMAQ.

References to the CMAQ program in ITS America’s 2002 report on the 10-year vision for ITS, underscore the importance of the CMAQ funding to the deployment of ITS. According to this report, one of the challenges for funding ITS deployment is that the ISTEA funding structure is oriented toward construction of facilities, and that “aside from Congestion Mitigation and Air Quality Improvement Program (CMAQ), Federal Aid funding programs do not focus on operations” (ITS America 2002, p 97). In the competition between operations and construction, where construction almost inevitably had the upper hand, the CMAQ provided one of the few outlets available for supporting deployment of ITS without having to compete with traditional infrastructure projects.

While CMAQ funds have played an important role in funding ITS-based operations, there are also important limits to the ability of the program to effectively support those operations. First, is the three-year limit on the use of CMAQ funds for specific projects, which covers only the “start-up” period of operations. Second, is the uncertainty about the levels of funding that will be distributed to each state and urban area, if either (1) new areas change attainment designation and become eligible for additional CMAQ funds, or (2) eligibility requirements are changed to allow for new areas to access CMAQ funds or allow for new project categories.
APPENDIX D. ELEMENTS OF INTERVIEW PROTOCOL

This appendix provides the material used during the site visits to Houston, Los Angeles, Boston, Orlando, and Tulsa. The potential interviewees were initially contacted either by email or by telephone to request an interview. They were given both the letter of introduction (see D.1), and the list of questions (see D.3). The question format was for open-ended questions, and was semi-structured, meaning that not all questions were asked of all participants, but depended upon their position, experience and knowledge of the issues.

The participants were also given a consent form for participation, as required by the Committee on the Use of Humans as Experimental Subjects (COUHES) (see D.2). The protocol was considered exempt after review by COUHES on May 17, 2005. The COUHES Protocol Number is 0505001221. All interviews were recorded, and written transcripts were made. Because direct quotes have been used, no identifiers to the participants have been used to protect confidentiality.

D.1 LETTER OF INTRODUCTION AND REQUEST FOR INTERVIEW

Date

Dear ____________:

I am contacting you to request an interview as part of a research study looking at air quality issues and Intelligent Transportation Systems (ITS) deployment in <CITY>. I am a doctoral candidate in the Technology, Management and Policy Program of the Engineering Systems Division at the Massachusetts Institute of Technology.

I will be conducting interviews with a range of stakeholders in five US cities as part of my doctoral dissertation research, which investigates the manner by which air quality regulations have influenced the deployment of Intelligent Transportation Systems technologies in the US. Your participation is being requested because of your role in transportation and/or air quality management. As part of this interview, I will be asking questions related to the general transportation and air quality planning process in <CITY>, the role of specific federal programs such as the Congestion Management and Air Quality Program (CMAQ); as well as questions about ITS deployments in <CITY> and their possible air quality impacts.

The interview should last approximately one hour. Your participation in this interview is voluntary.

If you agree to participate, have any further questions about this research, or have suggestions about additional individuals/agencies to interview, please contact me at dodder@mit.edu.

Your participation would be greatly appreciated. Thank you for your help.
Sincerely,

<SIGNATURE>
Rebecca Dodder
Doctoral Candidate
Technology, Management and Policy Program
Engineering Systems Division
Massachusetts Institute of Technology (M.I.T.)
D.2 CONSENT FORM FOR PARTICIPATION IN STUDY

You have been asked to participate in a research study conducted by Rebecca Dodder from the Technology, Management and Policy Program of the Engineering Systems Division at the Massachusetts Institute of Technology (M.I.T.). The purpose of the study is to assess the manner by which air quality regulations have influenced the deployment of Intelligent Transportation Systems technologies in US cities. The results of this study will be included in Rebecca Dodder's Doctoral thesis. You were selected as a possible participant in this study because of your role in transportation and/or air quality management and planning. You should read the information below, and ask questions about anything you do not understand, before deciding whether or not to participate.

• This interview is voluntary. You have the right not to answer any question, and to stop the interview at any time. We expect that the interview will take about 1 hour.
• You will not be compensated for this interview.
• Unless you give us permission to use your name, title, and/or quote you in any publications that may result from this research, the information you tell us will be confidential.
• We would like to record this interview on audio cassette so that we can use it for reference while proceeding with this study. We will not record this interview without your permission. If you do grant permission for this conversation to be recorded on cassette, you have the right to revoke recording permission and/or end the interview at any time.

This project will be completed by August 2005. All interview recordings will be stored in a secure work space until 1 year after that date. The tapes will then be destroyed.

I understand the procedures described above. My questions have been answered to my satisfaction, and I agree to participate in this study. I have been given a copy of this form.

(Please check all that apply)

[] I give permission for this interview to be recorded on audio cassette.

[] I give permission for the following information to be included in publications resulting from this study:

[] my name [ ] my title [ ] direct quotes from this interview

Name of Subject

Signature of Subject ___________________________ Date ____________

Please contact Rebecca Dodder at dodder@mit.edu with any questions or concerns.
D.3 INTERVIEW QUESTIONS

INTERVIEW QUESTIONS:
AIR QUALITY REGULATIONS &
INTELLIGENT TRANSPORTATION SYSTEMS (ITS) DEPLOYMENT

Draft: June 10, 2005

Case Study Sites
Non-Attainment: Los Angeles (extreme), Houston (severe-17), Boston (serious)
Attainment: Orlando, Tulsa

Researcher
Rebecca Dodder, Doctoral Candidate
Technology, Management and Policy Program, Engineering Systems Division,
Massachusetts Institute of Technology (MIT)

PART 1: Background

1.1. Could you describe briefly your position in [organization]? How long have you served in this role? How long have you worked for [organization]?

1.2. Have you worked for other organizations in [city] that work in the area of transportation or air quality?

1.3. Could you briefly describe your personal involvement, with your current or with former organizations, in air quality management in [city]?

1.4. Could you briefly describe your personal involvement, with your current or with former organizations, in Intelligent Transportation Systems deployment in [city]?

PART 2: Organizational Information

2.1. What is the role of your organization in transportation and/or air quality management in [city]?

2.2. How would you describe the core mission or vision of your current organization?

2.3. How have federal air quality regulations caused your organization to change or modify its existing operations or mission? How did your organization respond?

2.4. Which other organizations do you work most closely with? What is the purpose of that interaction? How would you describe the relationship with those organizations?

2.5. How have federal air quality regulations (TIP development, conformity, implementation of TCMs) changed those relationships?
2.6. Which other organizations do you work with regarding ITS? And regarding air quality? Is there any overlap in those functions (for example, implementing an ITS-based TCM included in a State Implementation Plan)?

PART 3: Metropolitan Transportation Planning

3.1. What are the major concerns and priorities for transportation planning in [city]?

3.2. What has been the most important impact of the 1990 Clean Air Act Amendments on transportation planning? How has it shaped those priorities?

3.3. To what extent has become more difficult, in the past 10-15 years to expand or add new highway and road capacity in [city], if at all? What are the principal reasons for that? What is the relative importance of: (1) meeting air quality conformity requirements, (2) the financial cost of new construction, (3) acquiring right-of-ways and related cost, environmental, and social issues?

3.4. Are there any examples of highway projects that were substantially affected by air quality regulations? What was the outcome?

3.5. To what extent have operational improvements been an important alternative to new highway and road capacity? What role does ITS play in those operational improvements?

3.6. Has there been increased emphasis on promoting public transit systems? What are the principal reasons for that? What is the relative importance of (1) congestion relief, (2) meeting air quality conformity requirements, (3) equity/access concerns, or (4) improving urban form.

3.7. What role has ITS played in improving public transit and increasing ridership?

3.8. To what extent has conformity encouraged investment in transportation strategies and technologies that improve air quality? To what extent has conformity encouraged investment in ITS?

PART 4: ITS Deployment

4.1. What have been the main motivating factor for deploying ITS?

4.2. What do you consider to be the most important ITS applications currently used in [city]?

4.3. What are their primary benefits?

4.4. Why were those particular ITS applications chosen? Was it because of their expected benefits, their political acceptability, technical feasibility, availability of funding, or other factors?

4.5. What role, if any, have federal ITS programs have in promoting ITS deployment in your metropolitan area? Which programs? Would those ITS deployments have taken place in the absence of that program?

4.6. What sources of revenue have been important to funding ITS?
4.7. Who were the main promoters or champions of those applications? What do you think their main motivation was?

4.8. Were there any people or organizations that opposed or resisted those applications?

4.9. Are there any ITS technologies which seemed promising, but weren’t implemented because of resistance from particular groups?

4.10. Has your organization been involved in the design, evaluation, or implementation of any ITS applications? Did those ITS applications build off of existing organizational capabilities, or require change on the part of your or other organizations, or even the creation of new organizations/agencies?

4.11. What role did your organization have in proposing, planning, evaluating, approving or implementing those applications?

4.12. Would you say those ITS technologies were a major or minor innovation for your organization?

4.13. Were any changes in your organization or its operations necessary in order to do that? For example, were new personnel required, reorganization, new procedures, etc.?

4.14. What are the most important expected benefits from ITS? What is the relative importance of those benefits to your organization? And to the city?

PART 5: ITS’ Air Quality Impacts

5.1. Are there any expected environmental benefits in terms of air quality, fuel use, or other possible environmental benefits from those ITS applications?

5.2. Have those benefits been studied? How were they measured or modeled, and what was the purpose or context of that study?

5.3. From your perspective, what impact does ITS have on emissions and air quality? Would you say they are definitely beneficial, neutral, or negative? How much uncertainty do you think there is regarding these impacts?

5.4. Is reduction of greenhouse gas emissions, specifically, carbon dioxide, a consideration for transportation planning? What about for ITS?

5.5. Which specific ITS applications do you think could affect local air quality?

5.6. Do you think those applications improve or worsen air quality?

5.7. What do you perceive to be the major uncertainties regarding the air quality impacts of ITS deployments?

5.8. How important is it that that uncertainty is resolved?
5.9. Do you feel that ITS has improved air quality in your city?

5.10. Does your organization or other organizations in your metropolitan area measure or model the air quality impacts of any ITS applications?

5.11. What is the context for those measurements? For example, are they used to meet any regulatory requirements?

PART 6: Transportation Control Measures (TCM)

6.1. How familiar are you with the Transportation Control Measures (TCM) used in [city]?

6.2. To the best of your knowledge, what TCMs have been or are planned to be implemented in [city]?

6.3. How important are TCMs to meeting mobile source emissions budgets or reducing the number of days above the NAAQS?

6.4. How are emissions changes from TCMs measured modeled? Who is responsible for doing that?

6.5. How many of those are ITS, or enabled or supported by ITS? How important are they compared to other TCMs?

6.6. Would these TCMs have been implemented otherwise, if not for purposes of meeting emissions reduction goals or conformity requirements?

6.7. Are all TCMs are included in the SIP? If some were not included, why is that?

6.8. Have any TCMs been particularly successful or unsuccessful? What were the main reasons these particular TCMs were chosen? For example, because of their emission reduction potential, political popularity/acceptability, technical feasibility, availability of funding, or other factors?

PART 7: Congestion Management and Air Quality Program (CMAQ)

7.1. Are you familiar with the Congestion Management and Air Quality Program (CMAQ)?

7.2. What role have CMAQ funds play in supporting ITS deployments, including traffic signal coordination, capital expenditures on Traffic Management Centers, Transportation Demand Management measures with an ITS component, etc?

7.3. Are there some specific ITS projects that you would like to discuss that were funded by CMAQ? Which agency was responsible for implementing those projects?

7.4. Were those projects designed primarily to improve congestion or air quality?

7.5. What would have happened to those projects in the absence of CMAQ funding?
7.6. Would you consider the primary goal of CMAQ to be congestion management or air quality?

7.7. How important would you consider the CMAQ program to overall air quality management in [city]? And to congestion management?
### Table E-1 Qualitative Scale for IIDAPT

<table>
<thead>
<tr>
<th>Core Activities</th>
<th>Supporting Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooperation</td>
<td>Innovation</td>
</tr>
<tr>
<td><strong>High</strong></td>
<td>More than one agency actively engaged in the design, deployment and/or operation.</td>
</tr>
<tr>
<td><strong>Low</strong></td>
<td>More than one agency indirectly involved or playing a supporting role in the design, deployment and/or operation.</td>
</tr>
<tr>
<td><strong>None</strong></td>
<td>No cooperation.</td>
</tr>
</tbody>
</table>

### Table E-2 Numerical Scale for IIDAPT

<table>
<thead>
<tr>
<th>Core Activities</th>
<th>Supporting Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooperation</td>
<td>Innovation</td>
</tr>
<tr>
<td><strong>High</strong></td>
<td>2</td>
</tr>
<tr>
<td><strong>Low</strong></td>
<td>1</td>
</tr>
<tr>
<td><strong>None</strong></td>
<td>0</td>
</tr>
</tbody>
</table>

### Table E-3 Scaling up to the Metropolitan Area

<table>
<thead>
<tr>
<th>ITS application areas</th>
<th>Representative technology</th>
<th>IIDAPT scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arterial traffic flow improvements</td>
<td>project</td>
<td>#</td>
</tr>
<tr>
<td>Freeway management strategies</td>
<td>project</td>
<td>#</td>
</tr>
<tr>
<td>Freeway traveler information</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>Transit information</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>Multi-modal information</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>Transit operational improvements</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>Transit fare payment systems</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>Rideshare support</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>Demand management/pricing</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td><strong>Other applications</strong></td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>-----------------------</td>
<td>-----</td>
<td>-----</td>
</tr>
<tr>
<td>Average level (0-6)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Range of IIDAPT (0-10)</td>
<td>= Average across application areas</td>
<td></td>
</tr>
<tr>
<td></td>
<td>= Number of application areas</td>
<td></td>
</tr>
</tbody>
</table>
Table E-4 Arterial traffic flow improvements: Regional Computerized Traffic Signal System (RCTSS)

<table>
<thead>
<tr>
<th>Core Activities</th>
<th>Supporting Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooperation</td>
<td>Innovation</td>
</tr>
<tr>
<td>High</td>
<td>2</td>
</tr>
<tr>
<td>Low</td>
<td></td>
</tr>
<tr>
<td>None</td>
<td></td>
</tr>
</tbody>
</table>

Air quality component: Funded through CMAQ and included as TCM.
Requires high levels of cooperation from City of Houston and Metro in upgrading signal hardware, providing interconnection to TranStar facilities, and optimizing signals. Includes simultaneous incorporation of transit signal priority by METRO.
Assessment focuses on emission reductions from traffic flow improvements, and not from transit priority. Assessment appears to be primarily ex-ante for reporting and funding eligibility purposes, in particular, for CMAQ funding. No discernable adaptation in response to new information for improvement of air quality outcomes.

Table E-5 Freeway management strategies: Computerized Transportation Management Systems (CTMS)

<table>
<thead>
<tr>
<th>Core Activities</th>
<th>Supporting Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooperation</td>
<td>Innovation</td>
</tr>
<tr>
<td>High</td>
<td>2</td>
</tr>
<tr>
<td>Low</td>
<td>1</td>
</tr>
<tr>
<td>None</td>
<td></td>
</tr>
</tbody>
</table>

Air quality component: Funded through CMAQ and included as TCM.
Primarily implemented by TxDOT. Operates from TranStar facilities. Cooperation with H-GAC in determining CMAQ eligibility and for incorporation as a TCM. Innovative in the high levels of integration surveillance, communications and control.
High levels of assessment of freeway speeds, travel times, and accidents. Continuous reporting of emission reductions in the TranStar annual report of overall emission reductions (although very rough estimates) and calculation of individual project benefits for CMAQ using MoSER guidebook.
No discernable adaptation for improvement of air quality outcomes.

Table E-6 Freeway traveler information: TranStar traffic map

<table>
<thead>
<tr>
<th>Core Activities</th>
<th>Supporting Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooperation</td>
<td>Innovation</td>
</tr>
<tr>
<td>High</td>
<td>2</td>
</tr>
<tr>
<td>Low</td>
<td></td>
</tr>
<tr>
<td>None</td>
<td></td>
</tr>
</tbody>
</table>
Air quality component: Not funded through CMAQ or included as a TCM. Highly innovative in terms of technology, and high levels of cooperation via TranStar for integrating various sources of information on travel times, incidents, construction, etc. Not considered IIDAPT because there is no explicit air quality objective in its deployment.

Table E-7 Transit information: Metro Trip Planner

<table>
<thead>
<tr>
<th>Core Activities</th>
<th>Supporting Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooperation</td>
<td>Innovation</td>
</tr>
<tr>
<td>High</td>
<td>2</td>
</tr>
<tr>
<td>Low</td>
<td></td>
</tr>
<tr>
<td>None</td>
<td>0</td>
</tr>
</tbody>
</table>

Air quality component: Not funded through CMAQ or included as a TCM. Not considered IIDAPT because there is no explicit air quality objective in its deployment.

Table E-8 Transit operational improvements: Integrated Vehicle Operation and Management System (IVOMS)

<table>
<thead>
<tr>
<th>Core Activities</th>
<th>Supporting Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooperation</td>
<td>Innovation</td>
</tr>
<tr>
<td>High</td>
<td>2</td>
</tr>
<tr>
<td>Low</td>
<td>1</td>
</tr>
<tr>
<td>None</td>
<td></td>
</tr>
</tbody>
</table>

Air quality component: Not funded through CMAQ nor included as a TCM. Not considered IIDAPT because there is no explicit air quality objective in its deployment.

Table E-9 Rideshare support: Online rideshare matching and mini-pool availability

<table>
<thead>
<tr>
<th>Core Activities</th>
<th>Supporting Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooperation</td>
<td>Innovation</td>
</tr>
<tr>
<td>High</td>
<td>2</td>
</tr>
<tr>
<td>Low</td>
<td></td>
</tr>
<tr>
<td>None</td>
<td></td>
</tr>
</tbody>
</table>

Air quality component: regional vanpool program included as a TCM. Highly innovative in providing information regarding the current availability of mini-vanpools and wait lists. Cooperation between H-GAC which manages the program, METRO which provides the vans and training and manages the HOV lanes, and transportation management organizations.

Table E-10 Demand management/pricing: QuickRide HOT lanes for the Northwest Freeway (US-290) and Katy Freeway (IH-10)

495
Air quality component: extension of HOV/ridesharing program.

Program initiated jointly by METRO and TxDOT, and includes involvement by Harris County, through the Harris County Toll Road Authority's electronic toll collection systems (EZTag). Also supported through H-GAC's commute solutions program. Innovative in the use of managed lanes for carpools (3+), vanpool, buses, and value pricing for (2+) carpools.

External and internal assessments, and adaptation to those assessments through changing policies regarding lane usage for maintaining a good "C" level of service. However, no evidence of adaptation in response to information regarding emission impacts.

Neither directly included as a TCM nor funded through CMAQ. However, it is included here because of its supporting role as a ridesharing strategy. We would not have included it if toll allowed for single occupancy vehicles.

Table E-11 Other applications: Online Reporting of Smoking Vehicles

<table>
<thead>
<tr>
<th>Core Activities</th>
<th>Supporting Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooperation</td>
<td>Innovation</td>
</tr>
<tr>
<td>High</td>
<td>2</td>
</tr>
<tr>
<td>Low</td>
<td>0</td>
</tr>
<tr>
<td>None</td>
<td></td>
</tr>
</tbody>
</table>

Air quality component: included as a Voluntary Mobile Emission Reduction Program (VMEP) measure.

Managed by the Texas Commission on Environmental Quality, marketing and advertising by H-GAC.

Little assessment undertaken. Because of the entirely voluntary nature of the program, the only information on how many vehicles are repaired is the self-reported information from vehicle owners.

However, not included as IIDAPT because there is no mobility benefit.

Table E-12 Scaling up to the Houston Metropolitan Area

<table>
<thead>
<tr>
<th>ITS application areas</th>
<th>Representative technology</th>
<th>IIDAPT scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arterial traffic flow improvements</td>
<td>RCTSS</td>
<td>4.5</td>
</tr>
<tr>
<td>Freeway management strategies</td>
<td>CTMS</td>
<td>4</td>
</tr>
<tr>
<td>Freeway traveler information</td>
<td>TranStar</td>
<td>--</td>
</tr>
<tr>
<td>Transit information</td>
<td>METRO Trip planner</td>
<td>--</td>
</tr>
<tr>
<td>Multi-modal information</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Transit operational improvements</td>
<td>IVOMS</td>
<td>--</td>
</tr>
<tr>
<td>Transit fare payment systems</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Rideshare support</td>
<td>RideShare matching/</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>mini-pool waiting list</td>
<td></td>
</tr>
</tbody>
</table>

496
Table E-13 Measures of IIDAPT for Houston

<table>
<thead>
<tr>
<th>IIDAPT measures</th>
<th>Average level</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demand management/pricing</td>
<td>QuickRide HOT lanes</td>
<td>4.5/6</td>
</tr>
<tr>
<td>Other applications</td>
<td>Online Smoking Vehicle Reporting</td>
<td>–</td>
</tr>
<tr>
<td>Average level (0-6)</td>
<td>4.5</td>
<td>4</td>
</tr>
<tr>
<td>Range of IIDAPT (0-10)</td>
<td>–</td>
<td>–</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>IIDAPT measures</th>
<th>Average level</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intensity (share of 2005-8 CMAQ projects)</td>
<td>37/84</td>
<td>44%</td>
</tr>
<tr>
<td>Intensity (share of 2005-8 CMAQ funding)</td>
<td>82 M / 306 M</td>
<td>27%</td>
</tr>
<tr>
<td>Intensity (share of 1994-9 TCM projects)</td>
<td>90/103</td>
<td>87%</td>
</tr>
<tr>
<td>Intensity (share of 1994-9 TCM funding)</td>
<td>78 M / 96 M</td>
<td>81%</td>
</tr>
<tr>
<td>Intensity (share of post-2000 TCM projects)</td>
<td>40/139</td>
<td>29%</td>
</tr>
<tr>
<td>Intensity (share of post-2000 TCM funding)</td>
<td>72 M /679 M</td>
<td>11%</td>
</tr>
</tbody>
</table>
Table E-14 Arterial Traffic Flow Improvements: ATSAC/ATCS

<table>
<thead>
<tr>
<th>Core Activities</th>
<th>Supporting Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooperation</td>
<td>Innovation</td>
</tr>
<tr>
<td>High</td>
<td>2</td>
</tr>
<tr>
<td>Low</td>
<td>1</td>
</tr>
<tr>
<td>None</td>
<td>0</td>
</tr>
</tbody>
</table>

Air quality component: CMAQ funding.
Developed and implemented by the City of Los Angeles DOT. Also implemented by Pasadena and other cities in Los Angeles County. Continual upgrading and adaptation of the system. ATCS is real-time adaptive to traffic conditions. Assessed the possibility of adaptation according to real-time CO levels, but project never implemented.

Table E-15 Freeway management strategies: ATMS/ATIS for Ports, closed circuit TV and changeable message signs

<table>
<thead>
<tr>
<th>Core Activities</th>
<th>Supporting Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooperation</td>
<td>Innovation</td>
</tr>
<tr>
<td>High</td>
<td>1</td>
</tr>
<tr>
<td>Low</td>
<td>0</td>
</tr>
</tbody>
</table>

Air quality component: CMAQ funded.
Cooperation between Ports of Long Beach and Los Angeles, and Caltrans. Includes addition of CCTV and changeable message signs to improve traffic operations on several interstates.

Table E-16 Transit Information: Transit trip planning tools

<table>
<thead>
<tr>
<th>Core Activities</th>
<th>Supporting Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooperation</td>
<td>Innovation</td>
</tr>
<tr>
<td>High</td>
<td>2</td>
</tr>
<tr>
<td>Low</td>
<td>1</td>
</tr>
<tr>
<td>None</td>
<td>0</td>
</tr>
</tbody>
</table>

Air quality component: several TMCs under the category of Information-based Strategies.
Variety of projects by Long Beach Public Transportation Co., City of Los Angeles, Foothill Transit, and SCAG. Experimentation with several approaches, including kiosks, online information, use of AVL, employer based trip planning tools, etc.

Table E-17 Multi-modal Information: CommuteSmart.info

<table>
<thead>
<tr>
<th>Core Activities</th>
<th>Supporting Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooperation</td>
<td>Innovation</td>
</tr>
<tr>
<td>High</td>
<td>1</td>
</tr>
<tr>
<td>Low</td>
<td>2</td>
</tr>
<tr>
<td>None</td>
<td>0</td>
</tr>
</tbody>
</table>

498
Air quality component: supporting component for transit, carpool, vanpool, and bicycle strategies.

Cooperation consists of a partnership between five counties. Los Angeles, Orange, Riverside, San Bernardino, and Ventura.

Table E-18 Transit operational improvements: AVL and communication systems

<table>
<thead>
<tr>
<th>Core Activities</th>
<th>Supporting Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cooperation</strong></td>
<td><strong>Innovation</strong></td>
</tr>
<tr>
<td><strong>High</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Low</strong></td>
<td></td>
</tr>
<tr>
<td><strong>None</strong></td>
<td></td>
</tr>
</tbody>
</table>

Air quality component: CMAQ funded, not typically included as TCMs. One project for included as TCM under Information-based Strategies, listing SCAG as the principal agency.

Assessment as part of CMAQ eligibility.

Table E-19 Transit fare payment systems: Universal Fare System Regional Project

<table>
<thead>
<tr>
<th>Core Activities</th>
<th>Supporting Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cooperation</strong></td>
<td><strong>Innovation</strong></td>
</tr>
<tr>
<td><strong>High</strong></td>
<td>2</td>
</tr>
<tr>
<td><strong>Low</strong></td>
<td></td>
</tr>
<tr>
<td><strong>None</strong></td>
<td></td>
</tr>
</tbody>
</table>

Air quality component: CMAQ funded

Project is primarily lead through Metro but includes cooperation through several transit agencies in Los Angeles County, including and City of Los Angeles, Santa Monica Municipal Bus, Antelope Valley Transit Authority, Gardena, Culver City Muni Bus Lines, Foothill Transit, Norwalk.

Incorporates smart card technology.

Assessment as part of CMAQ eligibility.

Table E-20 Rideshare support: Ridematch.info Database

<table>
<thead>
<tr>
<th>Core Activities</th>
<th>Supporting Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cooperation</strong></td>
<td><strong>Innovation</strong></td>
</tr>
<tr>
<td><strong>High</strong></td>
<td>2</td>
</tr>
<tr>
<td><strong>Low</strong></td>
<td></td>
</tr>
<tr>
<td><strong>None</strong></td>
<td></td>
</tr>
</tbody>
</table>

Air quality component: Ridesharing activities are CMAQ funded. web access information included as a TCM.

Cooperation on the ridematching databases for five counties. CMAQ funding used for ridesharing in Los Angeles, Riverside, San Bernardino, and Ventura counties as well. Includes more than a quarter of a million registered commuters.
Innovative in the ability to provide real-time matches to carpools and online information on availability of existing vanpools.

Table E-21 Demand management/pricing: SR 91 HOT lane (Orange County)

<table>
<thead>
<tr>
<th>Core Activities</th>
<th>Supporting Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cooperation</td>
</tr>
<tr>
<td>High</td>
<td>2</td>
</tr>
<tr>
<td>Low</td>
<td>1</td>
</tr>
<tr>
<td>None</td>
<td></td>
</tr>
</tbody>
</table>

Air quality component: Ridesharing measure, toll discounts for HOV 3+.
Innovative use of pricing for congestion management.
Cooperation with OCTA and Caltrans.
Air quality assessment undertaken for Caltrans by researchers from Cal Poly State University. Adaptation for refining dynamic pricing concept, but not for maximizing emissions reductions.

Table E-22 Scaling up to the Los Angeles Metropolitan Area

<table>
<thead>
<tr>
<th>ITS application areas</th>
<th>Representative technology</th>
<th>IIDAPT scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arterial traffic flow improvements</td>
<td>ATSAC/ATCS</td>
<td>5.5</td>
</tr>
<tr>
<td>Freeway management strategies</td>
<td>ATMS/ATIS for Ports</td>
<td>2.5</td>
</tr>
<tr>
<td>Freeway traveler information</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transit information</td>
<td>Transit trip planning tools</td>
<td>3</td>
</tr>
<tr>
<td>Multi-modal information</td>
<td>CommuteSmart.info</td>
<td>4</td>
</tr>
<tr>
<td>Transit operational improvements</td>
<td>AVL/comm. systems</td>
<td>2.5</td>
</tr>
<tr>
<td>Transit fare payment systems</td>
<td>Universal Fare Payment</td>
<td>4.5</td>
</tr>
<tr>
<td>Rideshare support</td>
<td>Ridematch.info</td>
<td>4.5</td>
</tr>
<tr>
<td>Demand management/pricing</td>
<td>SR 91</td>
<td>4</td>
</tr>
<tr>
<td>Other applications</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Average level (0-6) 3.8
Range of IIDAPT (0-10) 8

Table E-23 Measures of IIDAPT for Los Angeles

<table>
<thead>
<tr>
<th>IIDAPT measures</th>
<th>Average level</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3.9</td>
<td>8</td>
</tr>
<tr>
<td>Intensity (share of 2004-9 CMAQ projects)</td>
<td>49/214</td>
<td>23%</td>
</tr>
<tr>
<td>Intensity (share of 2004-9 CMAQ funding)</td>
<td>184 M / 1,154 M</td>
<td>16%</td>
</tr>
<tr>
<td>Intensity (share of post-2002 TCM projects)</td>
<td>34/268</td>
<td>13%</td>
</tr>
</tbody>
</table>

TCMs include projects that have a project end date of 2002 or after. Project start dates may go back to 1992. Projects included in the Final 2003 Air Quality Management Plan for the SCAG region.
CMAQ projects from the 2004 Regional Transportation Improvement Program. Included projects funded from FY 2004/5 to FY 2009/10, plus some carryover CMAQ funding from prior years.
Table E-24 Arterial traffic flow improvements: City of Boston TMC

<table>
<thead>
<tr>
<th>Core Activities</th>
<th>Supporting Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cooperation</td>
</tr>
<tr>
<td>High</td>
<td>1</td>
</tr>
<tr>
<td>Low</td>
<td>0</td>
</tr>
</tbody>
</table>

Cooperation between Boston MPO and BTD for including project within the CMAQ funding category and analysis of air quality benefits. Includes benefits from improved traffic flow improvements and transit bus performance (through optimizing signal priority system).

CMAQ funding (FY 2006-8) for expanded operations.

Table E-25 Freeway Management Strategies: Traffic Operations Center for Incident Management

<table>
<thead>
<tr>
<th>Core Activities</th>
<th>Supporting Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cooperation</td>
</tr>
<tr>
<td>High</td>
<td>1</td>
</tr>
<tr>
<td>Low</td>
<td>0</td>
</tr>
</tbody>
</table>

Cooperation between MHD, MassPike, and CPTS for inclusion in CMAQ funding.

Detailed modeling in the 1994 IVHS Strategic Plan for incident management.

CMAQ funding (1997).

Table E-26 Multi-modal information: SmarTraveler

<table>
<thead>
<tr>
<th>Core Activities</th>
<th>Supporting Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cooperation</td>
</tr>
<tr>
<td>High</td>
<td>0</td>
</tr>
<tr>
<td>Low</td>
<td>0</td>
</tr>
<tr>
<td>None</td>
<td>0</td>
</tr>
</tbody>
</table>

Reviewed because of early assessments of its air quality benefits. However, assessment cannot be commented upon because the full study could not be accessed.

Not included as IIDAPT because there was no explicit connection to air quality benefits through its funding or implementation.

Table E-27 Transit Operational Improvements: Transit Signal Priority (e.g., Silver Line and Route 39 buses)

<table>
<thead>
<tr>
<th>Core Activities</th>
<th>Supporting Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cooperation</td>
</tr>
</tbody>
</table>

502
Cooperation between City of Boston Transportation Department and MBTA. Also indirect support from the EOT and MHD. Cooperation with MassPort for priority for certain routes.

Both MBTA and BTD will monitor and review frequency of granting priority and impacts on crossing traffic. Changes to and expansion of program will depend on these results. Not clear whether review will include review of actual emissions impacts.

Table E-28 Transit Fare Payment Systems: CharlieTicket and CharlieCard

<table>
<thead>
<tr>
<th>Core Activities</th>
<th>Supporting Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooperation</td>
<td>Innovation</td>
</tr>
<tr>
<td>High</td>
<td>2</td>
</tr>
<tr>
<td>Low</td>
<td>None</td>
</tr>
</tbody>
</table>

Not implemented as part of a TCM nor funded through CMAQ.
No apparent assessment of air quality impacts of electronic fare collection.

Table E-29 Rideshare support: RideShare online matching

<table>
<thead>
<tr>
<th>Core Activities</th>
<th>Supporting Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooperation</td>
<td>Innovation</td>
</tr>
<tr>
<td>High</td>
<td>None</td>
</tr>
<tr>
<td>Low</td>
<td>1</td>
</tr>
</tbody>
</table>

MassRIDES (earlier known as Masspool Inc.) included as a TCM with the 1979 SIP. Considered an ongoing TCM.

Table E-30 Scaling up to the Boston Metropolitan Area

<table>
<thead>
<tr>
<th>ITS application areas</th>
<th>Representative technology</th>
<th>IIDAPT scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arterial traffic flow improvements</td>
<td>City of Boston TMC</td>
<td>2.5</td>
</tr>
<tr>
<td>Freeway management strategies</td>
<td>Traffic Operations Center</td>
<td>3</td>
</tr>
<tr>
<td>Freeway traveler information</td>
<td>SmarTraveler</td>
<td>–</td>
</tr>
<tr>
<td>Transit information</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Multi-modal information</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Transit operational improvements</td>
<td>Signal priority</td>
<td>4</td>
</tr>
<tr>
<td>Transit fare payment systems</td>
<td>CharlieTicket / CharlieCard</td>
<td>–</td>
</tr>
<tr>
<td>Rideshare support</td>
<td>Online rideshare matching</td>
<td>2</td>
</tr>
<tr>
<td>Demand management/pricing</td>
<td>–</td>
<td>–</td>
</tr>
</tbody>
</table>
Table E-31 Measures of IIDAPT for Boston

<table>
<thead>
<tr>
<th>IIDAPT measures</th>
<th>Aggregate level</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aggregate level</td>
<td>2.9</td>
<td></td>
</tr>
<tr>
<td>Range</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Intensity (share of 2006-8 CMAQ projects)</td>
<td>1/13 8%</td>
<td></td>
</tr>
<tr>
<td>Intensity (share of 2006-8 CMAQ funding)</td>
<td>1.15 M / 47.17 M 2%</td>
<td></td>
</tr>
<tr>
<td>Intensity (share of 1996-8 CMAQ projects)</td>
<td>3/18 17%</td>
<td></td>
</tr>
<tr>
<td>Intensity (share of TCM projects)</td>
<td>2/10 20%</td>
<td></td>
</tr>
</tbody>
</table>

The two ITS-based TCM projects include the Silver Line Bus Rapid Transit Service and Signal Prioritization. The Urban Ring commitment also anticipates the use of ITS for BRT-type services, however, the actual SIP commitment is to complete an Environmental Impact Report, meaning that its implementation is not certain.
### Table E-32 Freeway Management Strategies: Electronic Toll Collection (E-Pass)

<table>
<thead>
<tr>
<th>Core Activities</th>
<th>Supporting Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooperation</td>
<td>Innovation</td>
</tr>
<tr>
<td><strong>High</strong></td>
<td>1</td>
</tr>
<tr>
<td><strong>Low</strong></td>
<td>0</td>
</tr>
<tr>
<td>None</td>
<td>0</td>
</tr>
</tbody>
</table>

Good air quality assessment, but no explicit air quality objectives in the deployment or operation of the system. No adaptation to the information from the air quality evaluation. Therefore, not included as IIDAPT.

### Table E-33 Other applications: TravTek in-vehicle navigation field operation test

<table>
<thead>
<tr>
<th>Core Activities</th>
<th>Supporting Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooperation</td>
<td>Innovation</td>
</tr>
<tr>
<td><strong>High</strong></td>
<td>2</td>
</tr>
<tr>
<td><strong>Low</strong></td>
<td>0</td>
</tr>
<tr>
<td>None</td>
<td>0</td>
</tr>
</tbody>
</table>

Good air quality assessment, but no explicit air quality objectives in the deployment or operation of the system. No adaptation to the information from the air quality evaluation. Therefore, not included as IIDAPT.

### Table E-34 Scaling up to the Orlando Metropolitan Area

<table>
<thead>
<tr>
<th>ITS application areas</th>
<th>Representative technology</th>
<th>IIDAPT scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arterial traffic flow improvements</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Freeway management strategies</td>
<td>E-Pass</td>
<td>–</td>
</tr>
<tr>
<td>Freeway traveler information</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Transit information</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Multi-modal information</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Transit operational improvements</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Transit fare payment systems</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Rideshare support</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Demand management/pricing</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Other applications</td>
<td>TravTek</td>
<td>–</td>
</tr>
<tr>
<td><strong>Average level (0-6)</strong></td>
<td>0</td>
<td></td>
</tr>
<tr>
<td><strong>Range of IIDAPT (0-10)</strong></td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

### Table E-35 Measures of IIDAPT for Orlando

<table>
<thead>
<tr>
<th>IIDAPT measures</th>
<th>Average level</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Intensity</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
Table E-36 EAC Traffic Signalization Improvements

<table>
<thead>
<tr>
<th>Core Activities</th>
<th>Supporting Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooperation</td>
<td>Innovation</td>
</tr>
<tr>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>1</td>
<td>0.5</td>
</tr>
<tr>
<td>None</td>
<td>0</td>
</tr>
</tbody>
</table>

Cooperation between City of Tulsa, signal installation and modification, and INCOG, calculation of air quality benefits through consultant and incorporation in EAC.

Some novelty in using traffic signalization in an EAC to avoid a non-attainment designation. Earlier focus has been on all voluntary actions and episodic controls.

Table E-37 Tulsa RideShare Online Matching

<table>
<thead>
<tr>
<th>Core Activities</th>
<th>Supporting Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooperation</td>
<td>Innovation</td>
</tr>
<tr>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>None</td>
<td>0</td>
</tr>
</tbody>
</table>

Cooperation through INCOG.

Innovation in using on-line matching software for carpooling.

Part of Tulsa Clean Air program, not included as a TCM.

Table E-38 Ozone Alert! on VMS

<table>
<thead>
<tr>
<th>Core Activities</th>
<th>Supporting Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooperation</td>
<td>Innovation</td>
</tr>
<tr>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>None</td>
<td>0</td>
</tr>
</tbody>
</table>

Cooperation includes: ODEQ, ODOT, INCOG, and the Tulsa City/County Health Department.

Innovative in that they were first to use VMS as a notification system for high ozone alert days, and to promote alternative commuting and other measures as an episodic measure.

According to the EPA, an assessment protocol was developed.

Part of Tulsa Clean Air program, but not included as a TCM.

Table E-39 Scaling up to the Tulsa Metropolitan Area

<table>
<thead>
<tr>
<th>ITS application areas</th>
<th>Representative technology</th>
<th>IIDAPT scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arterial traffic flow improvements</td>
<td>EAC signalization</td>
<td>2.5</td>
</tr>
</tbody>
</table>

506
<table>
<thead>
<tr>
<th>Freeway management strategies</th>
<th>—</th>
<th>—</th>
</tr>
</thead>
<tbody>
<tr>
<td>Freeway traveler information</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Transit information</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Multi-modal information</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Transit operational improvements</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Transit fare payment systems</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Rideshare support</td>
<td>Online Match</td>
<td>2</td>
</tr>
<tr>
<td>Demand management/pricing</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Other applications</td>
<td>Ozone Alert!</td>
<td>4.5</td>
</tr>
<tr>
<td>Average level (0-6)</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Range of IIDAPT (0-10)</td>
<td>3</td>
<td></td>
</tr>
</tbody>
</table>

Table E-40 Measures of IIDAPT for Tulsa

<table>
<thead>
<tr>
<th>IIDAPT measures</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Average level</td>
<td>3</td>
</tr>
<tr>
<td>Range</td>
<td>3</td>
</tr>
<tr>
<td>Intensity (number of projects in EAC)</td>
<td>12/46</td>
</tr>
</tbody>
</table>
## E.7 FIVE-CITY COMPARISON

Table E-41 Five-city comparison of IIDAPT average levels and range

<table>
<thead>
<tr>
<th>ITS application areas</th>
<th>Houston</th>
<th>Los Angeles</th>
<th>Boston</th>
<th>Orlando</th>
<th>Tulsa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arterial traffic flow improvements</td>
<td>4.5</td>
<td>5.5</td>
<td>2.5</td>
<td>-</td>
<td>2.5</td>
</tr>
<tr>
<td>Freeway management strategies</td>
<td>4</td>
<td>2.5</td>
<td>3</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Freeway traveler information</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Transit information</td>
<td>-</td>
<td>3</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Multi-modal information</td>
<td>-</td>
<td>4</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Transit operational improvements</td>
<td>-</td>
<td>2.5</td>
<td>4</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Transit fare payment systems</td>
<td>-</td>
<td>4.5</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Rideshare support</td>
<td>4</td>
<td>4.5</td>
<td>2</td>
<td>-</td>
<td>2</td>
</tr>
<tr>
<td>Demand management/pricing</td>
<td>5.5</td>
<td>4</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Other applications</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>4.5</td>
</tr>
<tr>
<td><strong>Average level (0-6)</strong></td>
<td><strong>4.5</strong></td>
<td><strong>3.8</strong></td>
<td><strong>2.9</strong></td>
<td><strong>0</strong></td>
<td><strong>3</strong></td>
</tr>
<tr>
<td><strong>Range (0-10)</strong></td>
<td><strong>4</strong></td>
<td><strong>8</strong></td>
<td><strong>4</strong></td>
<td><strong>0</strong></td>
<td><strong>3</strong></td>
</tr>
</tbody>
</table>
### Table E-42 Freeway management strategies: Apoyo Vial motorist assistance

<table>
<thead>
<tr>
<th>Core Activities</th>
<th>Supporting Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooperation</td>
<td>Innovation</td>
</tr>
<tr>
<td>High</td>
<td></td>
</tr>
<tr>
<td>Low</td>
<td></td>
</tr>
<tr>
<td>None</td>
<td>0</td>
</tr>
</tbody>
</table>

No technological innovation, or innovation to improve air quality outcomes.

Program managed by Setravi. There does not appear to be any significant cooperation from other agencies such as the Secretary of Public Security. Therefore, this is not considered as IIDAPT.

### Table E-43 Transit operational improvements: Automated Vehicle Location (GPS) for Metrobus

<table>
<thead>
<tr>
<th>Core Activities</th>
<th>Supporting Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooperation</td>
<td>Innovation</td>
</tr>
<tr>
<td>High</td>
<td>2</td>
</tr>
<tr>
<td>Low</td>
<td>0.5</td>
</tr>
<tr>
<td>None</td>
<td></td>
</tr>
</tbody>
</table>

Cooperation between the Secretary of Environment as project lead, Secretary of Transportation and Roadways (Setravi), government-owned bus operators (RTP), and former microbus/colectivo operators and owners.

Innovative in the first use of GPS for control of bus fleets in Mexico City. Allows for better control of headways between buses.

No specific assessment of the contribution of AVL to emissions reductions. However, we assume that AVL will be used to guarantee the levels of service and frequency of service that use to model usage and overall air quality benefits from the project.

AVL still very new, therefore no opportunity yet to adapt system to improve air quality outcomes. Could be used to improve emissions profiles by reducing aggressiveness of accelerations coming out of stations.

### Table E-44 Transit fare payment systems: Smart Card for Metrobus

<table>
<thead>
<tr>
<th>Core Activities</th>
<th>Supporting Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cooperation</td>
<td>Innovation</td>
</tr>
<tr>
<td>High</td>
<td>2</td>
</tr>
<tr>
<td>Low</td>
<td>0.5</td>
</tr>
<tr>
<td>None</td>
<td></td>
</tr>
</tbody>
</table>

Cooperation between the Secretary of Environment as project lead, Secretary of Transportation and Roadways (Setravi), government-owned bus operators (RTP), and former microbus/colectivo operators and owners.
Innovative in the use of contactless and rechargeable smart card technology for pre-payment in station. Sales and recharging of smart card is automated through vending/recharging machines.

No specific assessment of the contribution of smart card to emissions reductions. However, consolidation of fare collection is considered integral to the ability to involve formerly private bus/microbus operators, by removing the cash transaction from the vehicle itself.

Adaptation of the Smart Card system – primarily, installation of additional card vending/recharging machines – based only on levels of service and queuing to enter station. Difficult to adapt system to improve air quality outcomes.

Table E-45 Scaling up to the Mexico City Metropolitan Area

<table>
<thead>
<tr>
<th>ITS application areas</th>
<th>Representative technology</th>
<th>IIDAPT scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arterial traffic flow improvements</td>
<td></td>
<td>N/A</td>
</tr>
<tr>
<td>Freeway management strategies</td>
<td>Apoyo Vial motorist assistance</td>
<td>N/A</td>
</tr>
<tr>
<td>Freeway traveler information</td>
<td></td>
<td>N/A</td>
</tr>
<tr>
<td>Transit information</td>
<td></td>
<td>N/A</td>
</tr>
<tr>
<td>Multi-modal information</td>
<td></td>
<td>N/A</td>
</tr>
<tr>
<td>Transit operational improvements</td>
<td>AVL for Metrobus</td>
<td>4.5</td>
</tr>
<tr>
<td>Transit fare payment systems</td>
<td>Smart Cards for Metrobus</td>
<td>4.5</td>
</tr>
<tr>
<td>Rideshare support</td>
<td></td>
<td>N/A</td>
</tr>
<tr>
<td>Demand management/pricing</td>
<td></td>
<td>N/A</td>
</tr>
<tr>
<td>Other applications</td>
<td></td>
<td>N/A</td>
</tr>
<tr>
<td>Average level (0-6)</td>
<td></td>
<td>4.5</td>
</tr>
<tr>
<td>Range of IIDAPT (0-10)</td>
<td></td>
<td>2</td>
</tr>
</tbody>
</table>