Managing Conflicts Between the Environment and Mobility: The Case of Road-Based Transportation and Air Quality in Mexico City

by

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B.S., Civil Engineering
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Submitted to the Department of Civil and Environmental Engineering
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Abstract

In the planning of transportation projects, there may be tradeoffs between providing mobility and achieving environmental objectives. Managing such potential conflicts is important to ensure that the economic benefits of efficient and effective transportation services are realized while the social and environmental externalities, such as air pollution, are minimized.

This thesis focuses on the case of the Mexico City Metropolitan Area (MCMA), arguably one of the largest and most polluted cities in the world. Air quality in the MCMA is of particular concern and motor vehicles are by far the largest contributors to emissions. The majority of all passenger trips in the region are served by road-based public transportation, particularly privately–operated microbuses and vans known as *colectivos*. Colectivos have been identified as a major contributor to congestion due to their competitive nature and self-regulated operating practices, and a contributor to air pollution in the region as well.

In general, public transportation is a highly visible sector that is subject to public scrutiny and regulation, and central to mitigating the negative impacts of increasing demand for mobility. In order to test the latter and explore the tradeoffs between mobility and emissions, a corridor model was developed. The results of the model show that giving priority to public transportation modes with dedicated rights-of-way and investing in new, larger vehicles may be effective strategies for reducing emissions and improving mobility for transit users. However, the net effect on total corridor mobility and emissions depends on numerous corridor parameters such as the level of congestion and the modal split.

Strategies were also explored to strengthen the implementation and sustainability of public transportation regulations towards the dual objective of enhancing mobility while decreasing emissions. By integrating public transportation modes, networks, and institutions, it is believed that improvements can be achieved in both mobility and transportation-related emissions in the MCMA.

Thesis Advisor: Joseph M. Sussman
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Acknowledgements

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Finally, my greatest debt of gratitude is to my parents and grandparents, who have sacrificed their whole lives for the well-being and success of their children. I thank God for the blessings my sisters and I have received. This work is dedicated to them.

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Chapter 1. Introduction

1.1 Motivation

In the planning and management of transportation systems, decision-makers may face financial and environmental challenges to providing efficient and effective mobility to city residents. With this in mind, public transportation often plays a key socio-economic role in large cities. Particularly in the developing world, road-based public transit is the major mode of transportation and often the only affordable option to the poor. Road-based public transportation, namely buses and other rubber-tire vehicles, can provide a flexible and cost effective means of moving large numbers of people. In Mexico City, all modes of road-based public transport serve about two-thirds of all motorized trips yet only constitute less than one in ten vehicles circulating the roads. Therefore, buses and other road-based transit modes are central to the success of any comprehensive public transportation system.

The objectives of a modern public transportation system are multi-dimensional and complex, usually including one or more of the following:

- To enhance the personal mobility of a significant portion of the population through reductions in travel times and/or improvements in service quality and coverage.
- To reduce or delay large investments in conventional infrastructure for surface transportation triggered by increasing volumes of low-capacity private vehicles.
- To provide a more efficient overall trip that accommodates the daily requirements of citizens considering the importance of access to the transportation system (i.e. complementary walking trips).
- To reduce the operational costs to yield the minimum total fare for the user's trip while considering the quality of services and socially-desirable fares.
- To reduce the use and dependence on private and low-capacity modes that produce higher social and environmental externalities by consolidating similar travel demands.

Personal mobility is a key ingredient in the economic activity of any region and subsequently in the quality of life of its residents. Similarly, the environment consumed in the form of air, water, and other resources is vital to human health and well-being. However, conflicts may arise between mobility and environmental objectives in the planning and management of transportation systems and services.

A prime example of such conflicts is the case of urban air pollution and public transportation in Mexico City. The ubiquitous microbuses and vans in Mexico City, known as *taxis colectivos,* provide a useful transportation service for millions of people daily but have been identified as a major contributor to congestion and air pollution in the region. Residents of the Mexico City Metropolitan Area (MCMA), including the entire Valley of Mexico, suffer from the consequences of high levels of air pollution in part due to topographic and atmospheric conditions and the concentration of activity in the region. Several decades ago, Mexico City was a much smaller metropolis whose residents enjoyed clean air and splendid vistas of the surrounding mountains. Today, however, Mexico City is arguably one of the largest and most polluted cities in the world whose residents have endured a severe decline in quality of life and arguably health.

The motivation for this research, therefore, is to improve or at least maintain the quality of life and ultimately the health of residents in the Mexico City Metropolitan Area through better management of road-based transportation, and particularly public transportation. It is believed that public transportation not only plays a key role in the region, but may also have a prominent role in reversing some of the negative trends. The underlying premise is that fundamental and complex relationships exist between transportation, the environment, and land use systems[1] as illustrated in Figure 1-1. For instance, cities and communities are not planned or built solely on the premise of supporting a pre-conceived notion of transportation, namely bus or rail transit systems. Rather, transportation supports land uses which, in turn, help shape transportation infrastructure in a symbiotic manner. In most cases, transportation services are not necessarily consumed for their own sake (with the possible exception of tourism) and must be planned with the other objectives in mind. Similarly, transportation directly and indirectly affects the built and natural environments just as the environment shapes and constrains transportation systems.

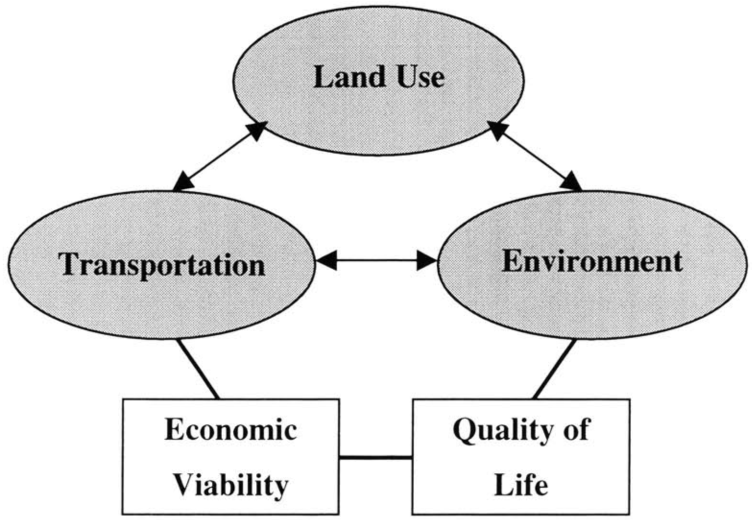

Figure 1-1: Fundamental Relationships between Systems
Source: Sussman (2000)

The primary focus of this thesis is the vital and complex relationship between road-based transportation and the environment, and the implications on economic viability and quality of life. It is intended to complement previous and current work on Mexico City by the MIT Integrated Program on Urban, Regional and Global Air Pollution.[2]

1.2 Transportation and the Environment

The transportation sector has numerous impacts on the natural and urban environments where we live. Petroleum consumption for transportation energy use is probably the most direct impact. The vast majority of petroleum in the world is refined for combustion in motor vehicles. About one-third of the transport energy use is currently consumed in the developing world and two-thirds in the developed world. In the next ten

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[1] Sussman (2000)
[2] Specifically, this thesis is intended to complement the current work on the Mexico City Metro and land use issues by Michael Gilat. Therefore, the focus is primarily on road-based public transport and not the Metro.

to twenty years, the split is projected to be even reflecting the expected growth in motor vehicle use in the developing world.

Closely tied to fossil fuel consumption is the issue of air pollution. At the urban and regional levels, the byproducts and trace species of combustion are often toxic to human health or have other negative impacts. However, through a combination of measures in the last few decades, urban air pollution has been significantly reduced in many areas of the developed world. For example, the frequency of days exceeding ozone and other urban pollutant standards set by the Environmental Protection Agency (EPA) for major metropolitan areas in the United States has dropped appreciably. At a much larger scale and subject to significant debate are so-called "greenhouse gases" including carbon dioxide (CO_2) that may lead to global climate change. Unlike other airborne pollutants, CO_2 emissions are directly related to the extraction of energy from fossil fuels through combustion and occurs naturally in the environment. Greenhouse gas emissions may prove to be a much more subtle yet pernicious environmental issue.

Noise pollution is yet another environmental impact of transportation. Although it is difficult to prove any noteworthy human health impact at low levels, noise can certainly be a significant annoyance to humans and other animals. It is particularly a problem in dense urban areas and often neglected in the developing world. Ecosystem degradation from the disturbing of the natural equilibrium between animals and habitats also appears to be very difficult to avoid and mitigate. Runoff from transportation infrastructure, containing oils, salt and dust, also has adverse environmental impacts such as water and soils contamination. The altering of topography and covering of surfaces with impervious materials may also cause flooding. Additionally, the disposal of millions of motor vehicles every year poses a serious solid waste problem.

Finally, traffic safety is still a huge social and environmental issue despite significant technological improvements in vehicle design in the last several decades. Especially where transportation modes with wide-ranging speeds and characteristics share roadways and paths, safety is a major concern. This is particularly common in the developing world where those at the bottom of the spectrum of transportation modes, such as bikers and pedestrians, are most vulnerable. In the short-run, the fatalities and injuries from traffic accidents may be more significant than any other environmental impact of transportation.[3] Nonetheless, Wright (2001) shows that there may be low-cost urban transport strategies that can synergistically decrease accidents, pollution, and energy use while improving mobility.

A recent Transportation Research Board committee on environmental sustainability concluded that greenhouse gas emissions and ecosystem degradation may be the greatest challenges to sustainable transportation.[4] On the other hand, the experience of the developed world in the last few decades shows that urban air pollution may be one of the most manageable problems associated with transportation. Because it appears to be one of the more controllable environmental impacts of transportation and because of the special issues faced in Mexico City, urban air pollution is the primary focus of this thesis henceforth.

1.2.1 Urban Air Pollution

Atmospheric pollution may be defined as the emission of substances that disturb the physical or chemical properties of the air. Combustion, employed to transfer useful energy, is the process in which most air pollutants are produced. Other human activities from manufacturing and chemical production may also generate pollution. The most important motivator for understanding and controlling urban air pollution are the associated negative health effects. Figure 1-2 is a schematic linking air pollution from human activities to the eventual health effects. In this chain, it is important to understand each component. For instance, the exposure to pollutants is different from the side of the road while waiting for a bus, than from the inside of an automobile in traffic.

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[3] Based on analysis in Ross (2000)

[4] Based on a presentation by John Heywood, MIT Professor of Mechanical Engineering, in April 2001.

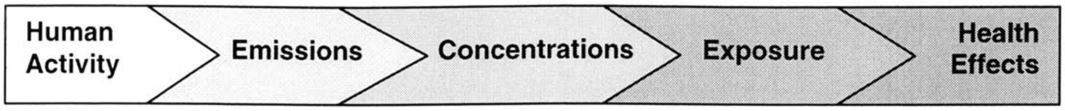

Figure 1-2: The Links between Human Activities and Health Effects[5]

The major pollutants are classified as primary and secondary. Primary pollutants typically remain unchanged in the atmosphere, while secondary pollutants chemically react with other substances to produce other pollutants, such as ozone. It is also important to understand the scale of air pollution impacts. Table 1-1 identifies three geographic dimensions of air pollution and the approximate time for the impacts to materialize.

Table 1-1: Categories of Air Pollution

Level	Examples of Pollutants	Effects	Time Scale
Local (City Center)	CO, Pb	Toxicity, Mortality	Short (hours)
Regional (Metropolitan Area)	NOx, VOC, PM, O_3, SO_2	Visibility, Morbidity, Chronic Health Effects	Short to Medium (days)
Global	GHG (CO_2)	Climate Change	Long (years)

Urban air pollution is at the scale of a city or metropolitan area and therefore is categorized as local or regional in impact. Examples of such pollutants are carbon monoxide (CO), lead (Pb), particulate matter (PM), sulfur dioxide (SO_2), and ozone (O_3). The effects range from reduced visibility in cities, to chronic diseases (such as bronchitis) that reduce human activity, to premature death and acute mortality. The chemical process and duration of urban air pollution tend to last from a few hours to a few days, whereas the impacts of greenhouse gases (GHG) is much longer in time.

[5] Based on presentation by Steve Connors for the MIT Integrated Program on Local, Regional, and Global Air Quality on 9 March 2001 at El Colegio de México.

1.2.2 Links to Transportation

All recent evidence indicates a close link between transportation and urban air pollution, especially in dense urban areas where human activity and transportation concentrate. Therefore, the intensity of transportation-related activities is a key factor in emissions. Some of the most important transportation-related components to air pollution are:

- Private Vehicles (automobiles, light trucks, etc.)
- Public Transportation
- Local and Regional Freight
- Fuel Distribution and Fugitive Emissions
- Unpaved Roads

Topographic and meteorological conditions, which vary greatly with each city or region, are also important determinants of air quality. For instance, a region of high altitude will have a lower oxygen atmosphere, which encourages incomplete combustion of fossil fuels. This has a significant impact on emissions. Wind patterns also play an important role in the link between urban air pollution emitted, the resulting concentrations, and the eventual health impacts.

The contribution of the transportation sector (i.e. mobile sources) to urban air pollution is different in various cities and regions. On an aggregate weight basis, about 40% to 50% of all emissions are from mobile sources in major metropolitan areas of the United States according to the U.S. EPA. Figure 1-3 presents data on five key pollutants according to the total amount emitted and the contribution of the transportation sector in the U.S. Depending on the pollutant considered, the specific contribution of transportation is from 3% to over 60%. These five most cited urban pollutants in the literature are particulate matter (PM), sulfur oxides (SOx), nitrogen oxides (NOx), carbon monoxide (CO), and volatile organic compounds (VOC). Lead has almost been eliminated in several countries but continues to be a serious problem where it is still used in gasoline.

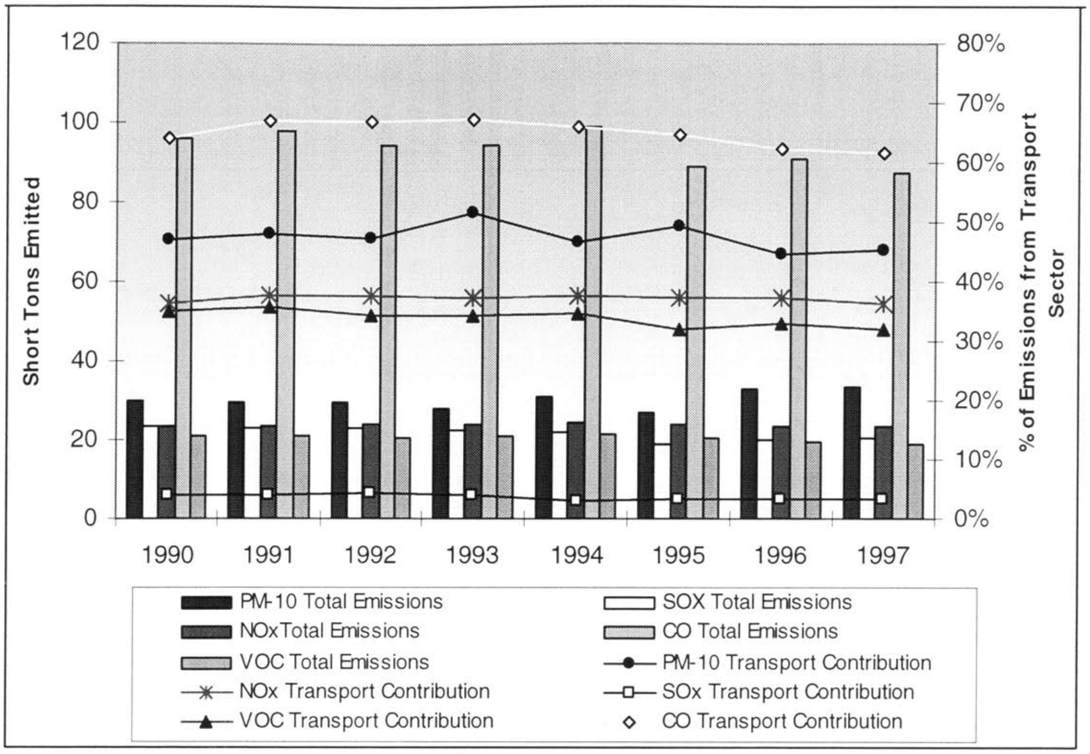

Figure 1-3: Emissions and Transport's Contribution in the United States

Source: U.S. Bureau of Transportation Statistics, National Transportation Statistics 1999

In some cities of the developing world, transport's contribution to emissions is higher due to higher population densities, congestion, or a more polluting vehicle fleet. In Mexico City, an estimated 60% to 80% of all emissions are from mobile sources.[6] There is significant variation in this estimate from emissions inventories in the past several years as can be seen in Table 1-2. It is not clear how much of the variation in the transport contribution is due to technological changes in the vehicle fleet, changes in transportation activities or patterns, or different methodologies and assumptions used in developing the inventories. Transportation consistently accounts for nearly all CO emissions. With regards to the precursors of ozone, transport accounts for about three-quarters of NOx and about one-third of VOCs. Most studies concur that ozone pollution in the region is NOx-limited, meaning that controlling NOx emissions is more effective in reducing ozone production.[7] The high share of NOx emissions attributable to transportation

[6] COMETRAVI (1999a) and CAM (2000)

[7] West et al. (2000)

suggests that strategies to control this pollutant would be an important part of an ozone abatement strategy. [8] The elimination of leaded gasoline sales in the MCMA in 1997 has effectively eliminated the contribution of transport to the concentration of lead.

Table 1-2: Transport's Contribution to Total Emissions in the MCMA – By Different Inventories[9]

	1994	1996a	1996b	1998
PM_{10}	4%*	25%	26%	51%
SOx	27%	21%	21%	28%
CO	100%	100%	99%	98%
NOx	71%	70%	77%	80%
VOCs	52%	33%	33%	36%

**N.B: in 1994, the contribution is of total suspended solids rather than just PM_{10}*

1.2.3 Characteristics of Key Pollutants

Carbon Monoxide (CO)

A colorless and odorless gas that impairs the absorption of oxygen by the blood. Therefore, exposure to certain concentration can be lethal. It also alters nervous system activity and causes changes in cardiac and pulmonary functions, causing headaches, fatigue, drowsiness, and respiratory failure. It is mainly derived from the incomplete combustion of fuels and other substances containing carbon. Wood fires are also an important source of carbon monoxide.

Volatile Organic Compounds (VOC)

This class of chemicals includes hydrocarbons (HC) and other organic compounds containing carbon and hydrogen in the gaseous state. In presence of sunlight, it may combine with nitrogen oxides and form photochemical "smog" or ozone. It is primarily produced from the incomplete combustion of fuels and other substances containing

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[8] Zegras et al. (2000)

[9] Data Sources: 1994 from Proaire, 1996a from the Proaire 2nd Report, and 1996b and 1998 from CAM (2000).

carbon and from the processing, distribution and use of oil derivatives such as gasoline and organic solvents. It is a known carcinogen and reduces respiratory system function.

Nitrogen Oxides (NO_X)

These are yellowish or brownish gases composed NO and NO_2 derived from high temperature combustion in industries and vehicle engines. It causes lung irritation, premature leaf loss and inhibition of plant growth, aggravates cardiovascular and respiratory diseases, and decreases visibility by contributing to ozone formation.

Ozone (O_3)

Low atmosphere ozone is a gas produced from the chemical interactions between NOx and VOC in the presence of sunlight. It is an unstable gas that oxidizes materials faster than oxygen. The adverse health effects of low atmosphere ozone include eye and respiratory system irritation and cardiovascular diseases. It also deteriorates some materials, interferes with plant growth, and decreases visibility. On the other hand, naturally occurring ozone in the upper atmosphere presents no adverse effects. Thus, the term ozone henceforth refers to the unhealthy, low atmosphere gas.

Sulfur Oxides (SO_X)

Sulfur oxides are mostly composed of sulfur dioxide (SO_2), which oxidizes and combines with water to form sulfuric acid (H_2SO_4), a main component of acid rain. It is derived from the combustion of coal, diesel, gasoline and other sulfurous fuels. It is also produced in mining and industrial processes and volcanic eruptions. The health effects include irritation of the eyes and respiratory system, reduction of pulmonary functions, and aggravation of respiratory diseases such as asthma, chronic bronchitis and emphysema. It also causes metallic corrosion, deterioration of electrical installations, paper, textiles, paints, construction materials, and historical monuments.

Suspended Particulate Matter (PM)

Particulate matter is composed of tiny suspended particles in the atmosphere such as dust, metals, cement, pollen, and organic compounds. The breathable fraction of all particles is constituted by those with diameters below 10 microns, also known as PM_{10}. These particles can penetrate the respiratory system, causing damage to the pulmonary alveoli. The main sources of PM are carbon materials used in industrial and domestic combustion, gasoline and diesel; industrial processes, fires, wind erosion and volcanic eruptions. There is some evidence that even smaller particles, on the order of 2.5 microns, from anthropogenic sources have different health impacts than coarser natural fugitive dust.[10] The general health impacts include irritation of the respiratory system, diseases like silicosis and asbestosis, and aggravation of other conditions such as asthma and cardiovascular diseases. It also has a deteriorating effect on buildings and plant life, decreases visibility, and induces cloud formation.

1.3 Background on Mexico City

1.3.1 The Mexican "Mega-City"

The largest city in the western hemisphere and the developing world is located in the North American continent as shown in Figure 1-4. Mexico City is the federal capital of Mexico as well as the financial and industrial center of the country. The city has a very special and vital function in the country's highly centralized government. In addition to the complexity of overlapping federal and local political jurisdictions, the MCMA also comprises a region that includes the *Distrito Federal* – DF (Federal District of Mexico) and the *Estado de México* - EM (State of Mexico).

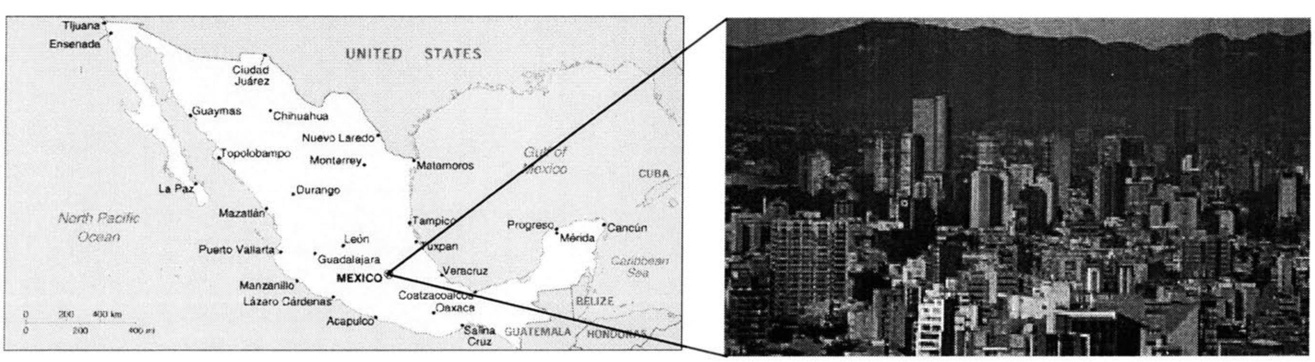

Figure 1-4: Mexico City, Mexico

[10] Evans et al. (2000)

1.3.2 Demographic and Socio-Economic Trends

The population of the DF was estimated at 8.49 million in 1996 by the United Nations. The population of the larger Mexico City Metropolitan Area (MCMA) was estimated at 16.56 million inhabitants with a projected population of 19.18 million by 2015. The MCMA produces over one-third of the country's gross domestic product (GDP) and represents nearly one-fifth of the country's population. Mexico's total GDP was USD$380.9 billion, making it the thirteenth largest economy in the world. The GDP per capita in 1998 was USD$3,970 according to the World Bank's World Development Indicators. In addition, more than 50% of Mexico's industrial output is produced in or near Mexico City. Manufactured goods include textiles, chemicals and pharmaceuticals, electrical and electronic items, steel, and transportation equipment. One of the largest manufacturing sectors in the region is automobiles and trucks; that industry exerts large financial and political influence in the country.

The Federal District of Mexico has a land area of 1,489 square kilometers and an average density of 5,700 inhabitants per square kilometer. The MCMA is made up of the sixteen *delegaciones* of the DF and at least twenty-seven surrounding municipalities in the EM covering an area of 4,604 square kilometers. Figure 1-5 shows the urban expanse of the MCMA as well as the recently urbanized areas in the darker shade. The historic center of Mexico City is the Zócalo which lies near the central business district (CBD).

Socio-economic patterns in Mexico City exhibit a higher concentration of wealth in the central city and a gradual decline in mean income as a function of distance from the center. This general pattern is markedly different from the spatial income distribution of large cities in most of the developed world and especially the United States. There are notable exceptions to this in the western and southwester parts of the DF where many middle-income and high-income residents live. The MCMA also exhibits large concentrations of poverty in the form of poorly constructed and illegal settlements ("*asentamientos ilegales*"). These settlements are unplanned and typically lack access to basic utilities and public transportation service.

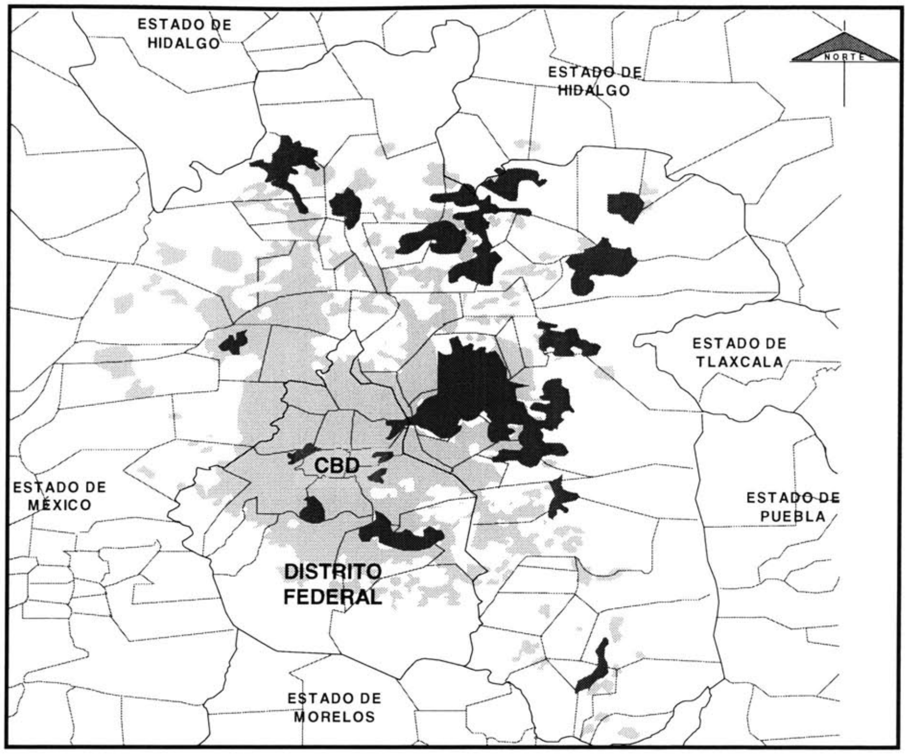

Figure 1-5: Mexico City Metropolitan Area
Source: COMETRAVI (1999) v.1

Since the 1970s, the MCMA has exhibited a strong tendency of decentralization. The highest population growth is currently occurring on the periphery of the MCMA, mostly in the EM due to the migration of low-income people from the countryside. Between 1970 and 1995, the "central city's" population declined by 1.7% to 2% per year, while the successive "rings" around the city absorbed a growing share of the city's population as show in Figure 1-6. This "urban sprawl" is expected to continue in the long-term encouraged by infrastructure expansion and policies diverting future growth to the outer rings or even *corona* (crown) cities 60 to 100 km from the central city such as Cuernavaca (State of Morelos) and Toluca (State of Mexico).

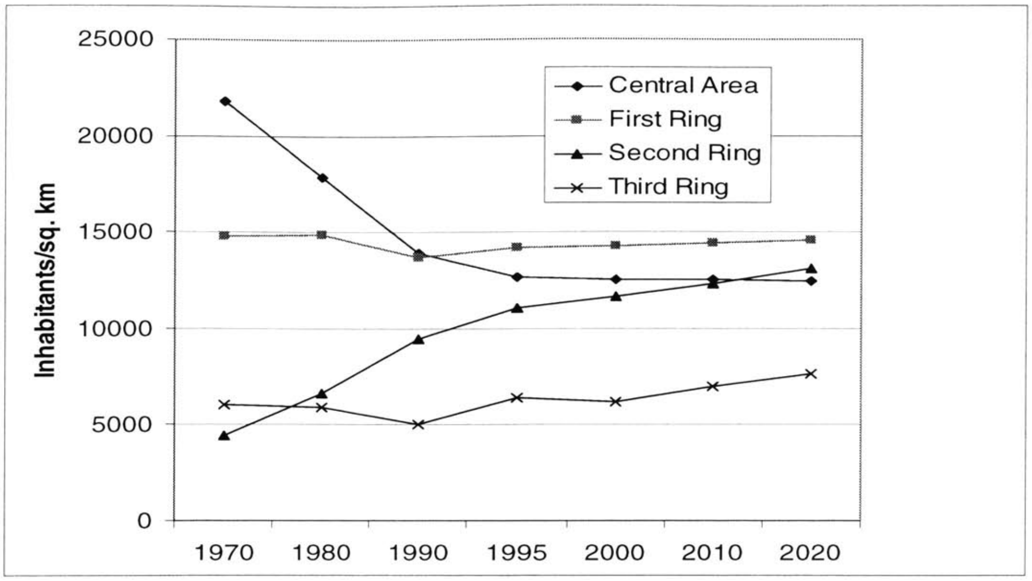

Figure 1-6: Evolution of Population Densities in the DF

Source: Villegas (undated) as cited in Zegras et al. (2000)

1.3.3 Transportation Infrastructure in Mexico City

Mexico City is a major hub for Mexico's transportation infrastructure. A large international airport is located east of the city center. Major highways and railroads radiate from the city to all parts of the country. However, road transportation in Mexico City is also chronically congested because of narrow, old streets and the explosive growth in population and motorization in the past few decades that outpaced infrastructure investments. The majority of roadway infrastructure is concentrated in the DF, as shown in Table 1-3. Figure 1-7 illustrates the layout of the major roadways and rail lines in the Valley of Mexico.

Table 1-3: Inventory of Major Roadway Infrastructure in the MCMA

Type of Roadway	DF	Urban EM	Units
Highways	200	352	Km
"Ejes Viales" or Urban Arterials	310	47	Km
Primary Roads	553	617	Km
Secondary Roads	8,000	n/a	Km
Intermodal Terminals ("Paraderos")	29	2	Stations

Source: COMETRAVI (1999) v.6, pp.15-16

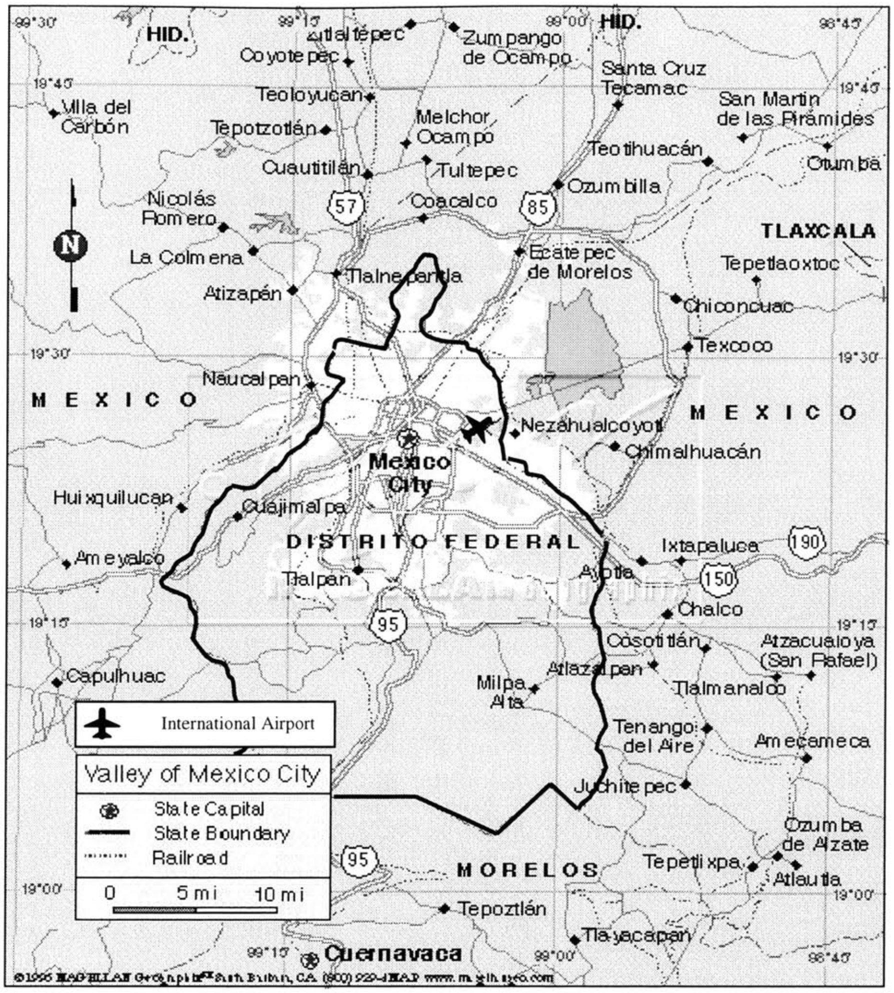

Figure 1-7: Roadway and Railroad Infrastructure in the Valley of Mexico City

An important improvement, the first subway line, began operating in 1969. A diagram of the expansive current Metro system comprising 11 lines, 178 km of heavy rail and 26 km of light rail, and about 170 station is shown in Figure 1-8. The oldest three lines (i.e., 1,2, and 3) carry over 60% of the passenger trips daily and are some of the most heavily used lines in the world.[11]

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[11] SETRAVI (1999)

Figure 1-8: Mexico City Metro Network

1.3.4 Road-Based Public Transport

Typically, when the mobility needs of city residents are not fully met by the conventional transportation system, alternative transportation services may legally or illegally emerge from the private sector. These services are sometimes known as *informal* transportation or *jitney* services. In all cities where the service exists, it is an intermediate option that supplements or perhaps exploits the weaknesses of the conventional public bus and rail systems with varying degrees of success.

In the case of the MCMA, the informal public transportation sector, more aptly referred to as *taxis colectivos,* operate in a manner between the conventional bus and the taxi. They comprise about 32% of all vehicles in the *servicios de transporte concesionados* (transportation services under concessions), which include all taxis, colectivos, and contracted bus services. More than 50,000 *microbuses* and *combi* (i.e. 10-12 passenger vans) operate as colectivos in the MCMA and serve over 16 million trip segments per day.[12] This translates into 55% of all motorized person-trips in the Mexico City Metropolitan Area. Just in the *Distrito Federal (DF),* there are about 27,000 licensed colectivos marginally regulated by government concessions, the number of which has been frozen since 1986. In addition, tens of thousands of additional unlicensed vehicles are tolerated in the *Distrito Federal* and the surrounding *Estado de México (EM).* The sheer number of vehicles compounded by erratic driving and on-street vehicle storage has exacerbated the congestion and air pollution problem in Mexico City. By comparison, there are less than 2,500 full-size buses operating in the DF— about half under the publicly-operated Red de Transportes Público (RTP) and the other half under contract to 9 private companies.[13]

Since the privatization of the public transport sector in the 1980s, Mexico City has witnessed the evolution of the colectivo mode from taxi sedans to combis of 10 to 18 passengers, and finally microbuses with a capacity of 20 to 25 seats and an additional 10 to 15 standing passengers. This suggests a long-term trend towards larger vehicles; yet smaller vehicles have inherent advantages over conventional high-capacity buses in terms of service and flexibility. The most important advantage is the higher frequency of service compared to conventional transit due to smaller vehicles and/or shorter vehicle cycles. By diversifying transit options and providing a higher level of service and coverage, colectivos are able to capture the public's willingness to pay for transportation services. These advantages of colectivos and others help explain the precipitous mode share decline of the public bus in the last decade to less than ten percent of motorized passenger trips. The microbuses often compete directly with the extensive Metro network and the weakened bus network, thereby capturing a majority of the public transportation trips.

[12] COMETRAVI (1999) v.1
[13] Presentation by Florencia Serrania, SETRAVI, on 9 March, 2001 at El Colegio de México.

Jitney or informal public transportation services in Latin American cities alarm many government and public transportation officials due to the perceived negative impact on metro and bus ridership and on-street congestion. The rise of the informal mode share in other Latin American megalopolises, such as São Paulo and Rio de Janeiro, has alerted government and public transportation officials to the possibility of a similar decline in metro and bus ridership and a parallel increase in informal transportation modes.

1.4 Objectives

The ultimate objective of this thesis is to understand and work towards achieving a balance between mobility and environmental objectives that optimizes the level of economic activity, health, and social welfare through the planning, regulation, and management of road-based public transit. This undoubtedly involves understanding and modeling the dynamics behind the supply and demand of transportation services and their operations. The central question is how air quality can be improved while maintaining or enhancing mobility in Mexico City.

Buses, colectivos, taxis, and private vehicles share most major roads in Mexico City. Comprehensive studies published by COMETRAVI (Metropolitan Commission for Transportation and Highways) in 1999 characterize the present modal distribution as inefficient primarily because the majority of the demand is being served by low-capacity public transportation vehicles (microbuses and vans) which results in large quantities of vehicles on the roads contributing to traffic congestion and emissions. The studies also contend that the large mode share of colectivos increase infrastructure requirements in the form of urban road space and intermodal transfers facilities. The report concludes that this situation is also disadvantageous for the service providers, who may have lower individual investment and operation costs but incur larger system-wide costs. This inefficiency directly results in the transferring of costs to riders in the form of higher fares and environmental externalities such as air pollution.[14] This work is intended to test these notions by analytically modeling road-based traffic on high-demand corridors and varying key parameters. It also will suggest regulation and integration strategies that may improve the operations and externalities associated with road-based transportation.

1.5 Methodology

This study aims to achieve its objectives and address the research question by applying the methodology illustrated in Figure 1-9. The following are the detailed steps involved.

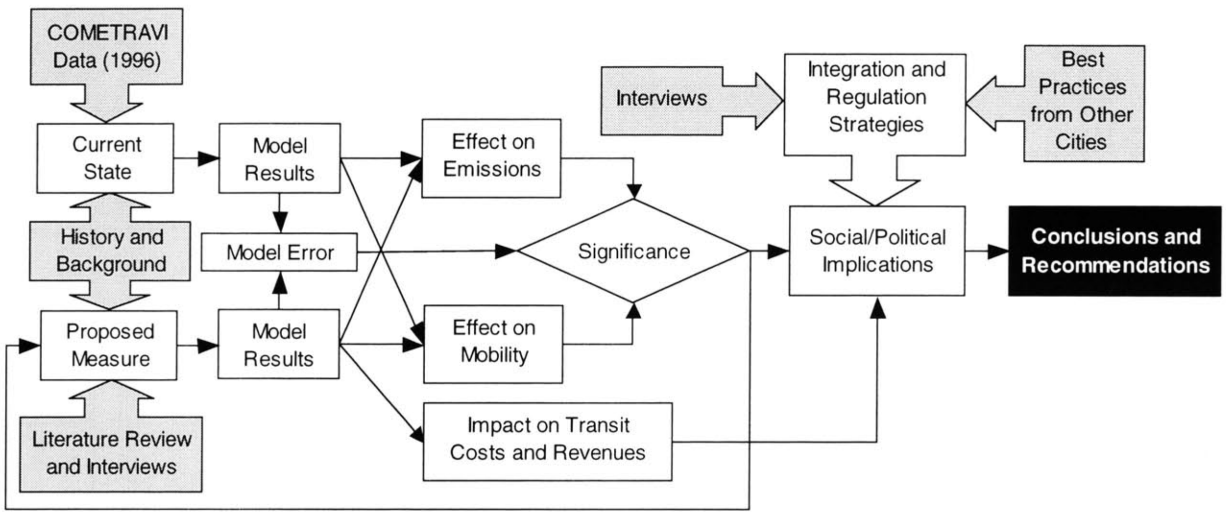

Figure 1-9: Research Methodology

1. Perform a literature review on the links between transportation and urban air pollution, transportation measures to reduce emissions, and the effects on personal mobility.
2. Investigate the state of urban transportation in Mexico City and compare its public transportation with other large cities, particularly in Latin America. The investigation includes a literature review and interviews with key Mexican officials, representatives, and experts.
3. Explore strategies for the integration and regulation of public transportation modes— public and private, formal and informal. This includes urban

[14] COMETRAVI (1999) v.7

transportation strategies of international organizations and multilateral lending institutions such as the World Bank and Inter-American Development Bank.

4. Examine the history, operations, and organization of the *taxis colectivos* in Mexico City.
5. Develop and test an equilibrium model that analyzes the operations of private and public transportation modes on major corridors in Mexico City. The model utilizes the best information available on public transportation modes to simulate the operating policies, costs, fares, and competition between modes.
6. Identify measures to be tested based on history and literature review. These options include:
   - Varying the operations or characteristics of road-based public transportation modes such as vehicle size, fares, and frequency of service
   - Reserving or installing new exclusive public transportation lanes
   - Replacing microbuses for full-size buses
7. Use the corridor model to test the sensitivity of key parameters such as total demand and road capacity to mobility costs and emissions.
8. Develop mobility and emissions evaluation framework.
9. Use the corridor model to evaluate the impact of measures based on both mobility and emissions objectives. Eliminate the systematic error by finding the difference between model predictions with and without the tested measure.
10. Test the significance of the measures based on the model error to the actual data.
11. Revise and combine measures to create optimal packages.
12. Develop regulation and integration strategies for public transportation that may strengthen measures that improve mobility and/or emissions based on the most recent literature, best practices from around the world, and interviews.
13. Evaluate the political and social implications of the most promising measures and suggest regulation and integration strategies to strengthen their political and social acceptability.
14. Draw conclusions and recommendations for the Mexico City case based on key findings.

1.6 Thesis Organization

The topics and questions to be addresses in this thesis are organized into the following five chapters:

Chapter 2: Mexico City's Colectivos and the Urban Transport System

- What is the history of the *taxis colectivos* and urban transportation in Mexico City? What is the current regulatory environment and how does it affect colectivo operations and management?
- What is the current state of urban transportation with respect to both public and private modes? What are the dynamics driving the supply and demand for public transportation? Who are the stakeholders involved?
- What is the general political environment and objectives with respect to air quality, personal mobility, and economic growth in Mexico City?

Chapter 3: Modeling Road-Based Public Transportation

- The contribution of all mobile sources has been estimated in Mexico City to be about around three-quarters of all emissions.[15] The same emissions data of key pollutants also show that the contribution of road-based public transportation is not nearly as significant as that of trucks or private vehicles. However, since all these modes typically share the same roads and traffic congestion, measures to improve the management and operations of public transportation may significantly reduce total emissions. The question is: how is it possible to quantify the impacts of proposed measures to public transportation on mobility and emissions?
- Present the evaluation framework and the major assumptions for the corridor model. Discuss its applications and numerous limitations.
- How do the size, fare, frequency, and other operational characteristics of surface public transportation vehicles affect the mobility of residents and vehicular emissions in a transportation corridor?

[15] CAM 1994 Emissions Inventory as cited in COMETRAVI (1999) v.1

- Develop a framework for evaluating the impacts of proposed measures on mobility and emissions based on the corridor model results.
- Discuss the findings and unintended consequences of a variety of tested measures.

Chapter 4: Regulation of Road-Based Public Transportation

- What are the possible roles of the public and private sector for the provision of public transportation? What are the dynamics of the interaction between the public and private sectors? What is the role and impact of *intermediate* or *informal* transportation services?
- What are some issues specific to Latin America and the rest of the developing world? In light of these, what are some strategies to strengthen the regulation and management of public transport?
- How is it possible to balance competition and coordination of transportation services in Mexico City? What are the experiences and best practices from other cities?

Chapter 5: Integration of Transit Services

- How can modal integration be achieved between public transportation modes in Mexico City? What are the characteristics, advantages, and disadvantages of *intermediate* or informal transit modes?
- What are the forms of network integration and which may apply to Mexico City?
- What is the state and potential for institutional integration in Mexico City?
- How can technological options, such as "smart cards", be used to integrate and coordinate modes in Mexico City?
- Finally, what are the potential impacts of integration on emissions?

Chapter 6: Conclusions

- Summary and Review of Key Findings
- What are the lessons from other megalopolises of the developing world with respect to mobility and air quality? What are the lessons from Mexico City?
- What can be expected in the future of urban transportation in Mexico City?
- Areas for Future Research

Chapter 2. Mexico City's Urban Transport System

2.1 History of the Colectivos in Mexico City

2.1.1 The 1940s to 1970

The second half of the 20th century was a period of rapid urbanization and high population growth in Mexico City. As evidence of this, the expansion of the urban footprint from 1940 to 1990 is illustrated in Figure 2-1. In 1940, the population of Mexico City was under 2 million and the urban area was almost entirely within the DF. By the year 2000, about half of the metropolitan area's 17 million residents live in the EM. The result is that gross densities for the MCMA remained relatively stable since 1940, about 160 inhabitants per hectare.[16]

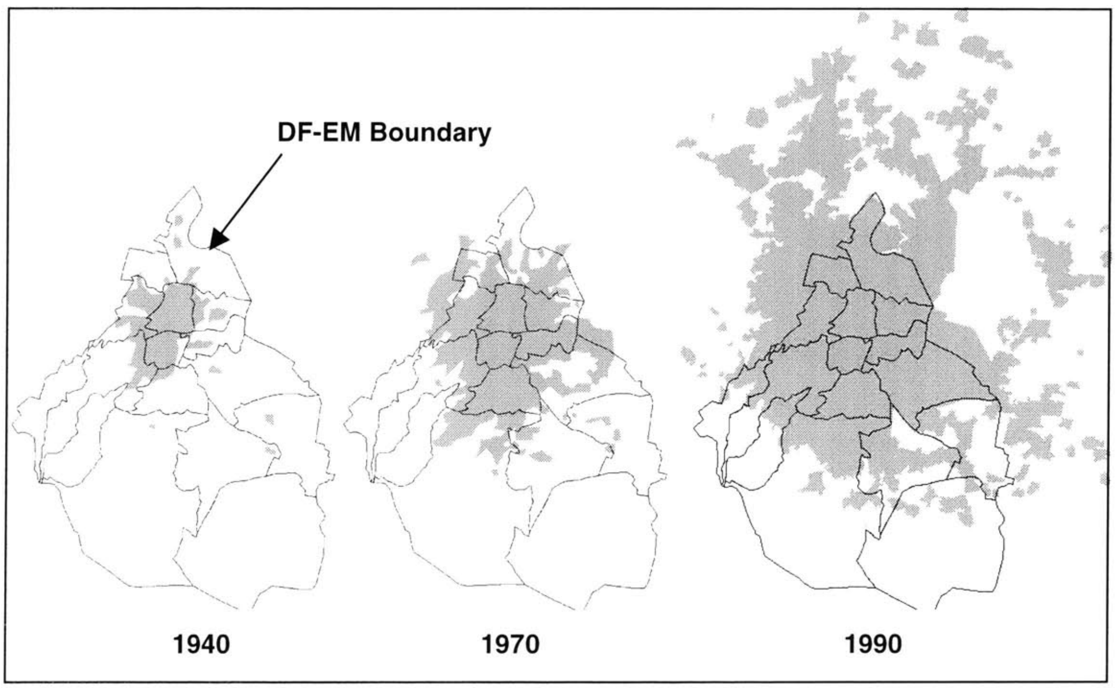

Figure 2-1: Evolution of the Urban Footprint from the DF to the EM

Source: Lemus (1998)

[16] Cervero (1998), pg. 392

In the 1940s, urban buses carried up to 70% of the trips in the city. The urban bus services were tendered by the government to private companies and groups belonging to the "Alianza de Camioneros de México" (ACM).[17] By the early 1950s, the first *taxis colectivos* appeared using the same sedans of the recognized taxi services. In this early period, the colectivos did not necessarily have fixed routes but functioned much like collective or shared-ride taxis. These vehicles were officially illegal but tolerated by the government in the beginning. In this sense, the colectivos were an *informal* public transportation mode that survived by supplementing the service of the dominant public transportation modes of the era. Their ability to avoid systems of control and entrepreneurial nature were common to other areas of the informal sector, such as informal street vending.[18] The service was then fully recognized in the late 1960s and administered by the first organization of regular and collective taxis, the *Coalición de Agrupaciones de Taxistas* (CAT).

In 1946, the foreign company that operated the electric trolleys in Mexico City, "Servicios de Transportes Eléctricos del Distrito Federal" (STE), was nationalized marking the first time the government became directly involved in the provision of public transportation. The STE operated the electric trolleys that at the time was a much more significant mode of public transport. The second public transport entity operated by the government, the "Sistema de Transporte Colectivo-Metro" (STC-Metro), was created in 1967 to operate the new subway system that was opened in 1969. At that time, the transportation planning authority for the DF and the regulating agency for colectivos, the "Coordinación General de Transporte" (CGT), began issuing licenses only to colectivo routes that fed Metro stations.[19]

2.1.2 From 1970 to 1976

This period was marked by the inclusion of transportation planning as a bona fide government function. Nevertheless, the expansion of the Metro was suspended by

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[17] Roldán et al. (2000)
[18] Based on a presentation given by John Cross of Vassar College on 3 March 2001 at MIT.

presidential decision only to be resumed in the late 1970s. The "regent" of Mexico City and head of the DF government at the time was a member of the "official" political party, the PRI, and was appointed by the president.[20] As a lawyer for the ACM, his political ties to the organization were evident by the generous support and liberties the government provided the bus interests. These included:

- High government subsidies,
- Government-backed credits and loans,
- Differentiated fares by level of service, and
- Legal control over driver organizations.

2.1.3 From 1976 to 1982

The late 1970s and early 1980s was marked by a significant change in the government's role and policy of investments in public work projects. In this period, the Metro system was extended and a new network of major boulevards coined *ejes viales*, or axial roadways, was created. These roadways were intended to serve as major arterials to alleviate the growing traffic congestion.

By 1982, the Metro had a total track length of 78 km, 80 stations, and 4 lines. The French pneumatic-tire technology allowed the Metro better acceleration and deceleration for shorter station spacing and negotiating tighter turns. Despite its higher maintenance, rubber tires absorb some of the vibrations and make the Metro more comfortable and better suited for Mexico City's unstable soils.[21] The growth in Metro ridership during this period can be seen in Figure 2-2. Urban buses and suburban express buses remained the dominant mode in the MCMA at the time but their share of trips began declining by the mid-1980s. Also noteworthy from Figure 2-2 was that the rate of trip growth for the region during 1979 to 1986 was lower than the previous or following periods. The most plausible explanation was a weak Mexican economy.

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[19] Cervero (1998), pg. 393

[20] Until 1997, when the first gubernatorial election was held, the government of Mexico City was called the "Departamento del Distrito Federal" and was appointed by the president of the republic.

[21] Cervero (1998)

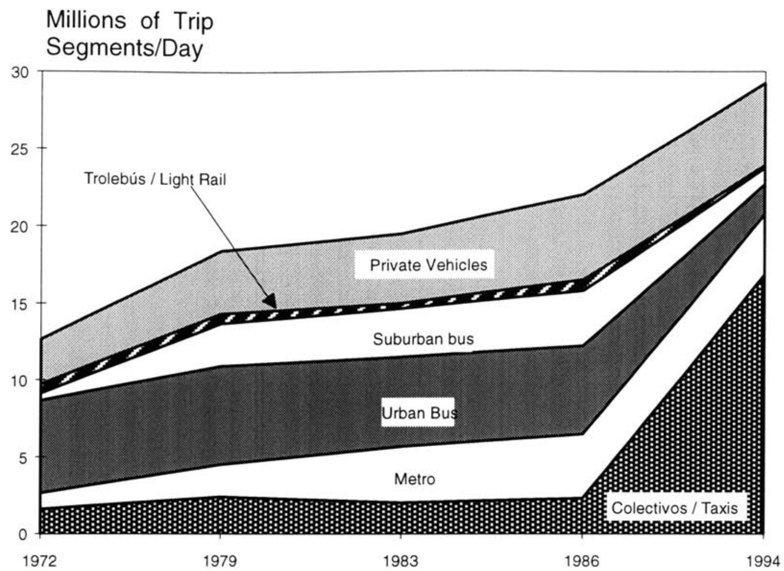

Figure 2-2: Trip Segments in the MCMA by Mode
Source: COMETRAVI (1999) v.1

The municipal government (DF) of this period also became integrally involved in the management and coordination of transportation services through the *Comisión de Vialidad y Transporte Urbano* (COVITUR). COVITUR was the entity responsible for roads and urban transport as well as the planning, designing, and construction of transportation projects. Moreover, it coordinated other institutions and produced the DF's Roadway and Transportation Master Plan for 1977-1982.[22]

In 1981, a new public bus organization, *Autobuses Urbanos de Pasajeros Ruta-100* (AUPR-100 or simply Ruta-100), was created in the DF to replace the ACM whose government concessions were terminated. At its inception, the Ruta-100 was not able to serve the demand left by the absence of the ACM buses. As an immediate solution, the government permitted and even stimulated the expansion of taxis colectivos over the next few years. As a result of the growth, new colectivo organizations were formed that forged relationships with the transportation authorities and the replacement of the sedans for higher-capacity units of at least ten passengers (*combis* or *vagonetas*) was financed by local government loans. These new and tolerated colectivos were accepted and promoted

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[22] Roldán et al. (2000)

by politicians and organizations. Therefore, the most significant result of this period is the inclusion of the concessionaires of the new colectivos as official stakeholders in the political landscape of metropolitan transportation.[23]

2.1.4 From 1982 to 1988

The growth in the colectivo mode became evident by the late 1980s as low-capacity modes including taxis, colectivos, and private vehicles reached parity with the high-capacity modes such as the bus, Metro, and trolleybus. Table 2-1 details the evolution of mode shares by presidential administration. This shift from high to low-capacity modes continued into the 1990s.

Table 2-1: Evolution of Low and High Capacity Mode Shares, 1970-2000 –By Presidential Administration *(Adapted from Navarro, 2000)*

Vehicle Capacity	Representative Modes	1970-76 Echeverría	1976-1982 López Portillo	1982-88 De la Madrid	1988-94 Salinas	1994-2000 Zedillo
Low-Capacity	Taxis, Colectivos, and Private Vehicles	31.5%	32.2%	32.1%	49.0%	75.8%
High-Capacity	Metro, Buses, and Trolleybuses	66.6%	65.5%	67.2%	51.0%	22.9%
Other		1.9%	2.3%	0.7%	--	1.3%
Total		100.0%	100.0%	100.0%	100.0%	100.0%

The earthquakes of 1985 and growing environmental problems radically modified the federal and local urban policies in Mexico City. Urban air pollution was recognized as a serious problem by the government and inseparable from urban planning in several important government documents on urbanization and land development.[23] The Mexico City government also attempted to reduce spending on all urban services, including public transportation, by deregulation. This reduced role of the government drove the growth of the colectivos and the continued mode share decline of the government-operated modes. By the late 1980s, colectivos had assumed dominance over road-based public transport (see Figure 2-2). Emblematic of this triumph, the colectivos were

[23] Roldán et al. (2000)

incorporated as feeders in the design of new Metro stations for the first time in the late 1980s.

The government of the DF also attempted to regulate the number of concessions in 1985 but the political pressures and the need to create sources of employment softened the policy. The number of concessions continued to increase rapidly. By the late 1980's, the government participation in the provision of road-based public transportation began a precipitous decline as can be seen by the mode shares of the urban and suburban buses in Figure 2-2 after 1986. This decline was fueled by falling ridership, decreased revenues, and deferred maintenance practices of the Ruta-100 system in a self-reinforcing manner. The origin of this "vicious cycle" in publicly-operated bus services was arguably driven the explosive growth in colectivo ridership and fleet.

At the same time the colectivo mode was "consuming" the lost mode share of the bus, it was able to increase its patronage by improving its level of service and therefore its attractiveness relative to the bus. This dynamic can be aptly represented using the concepts of "system dynamics," as shown in Figure 2-3.[24] This model, developed by Yoshikazu Shimazu, Osama Uehara, and Chris Zegras, is externally influenced by alternative employment opportunities, which was identified as a major factor in the growth of the colectivo mode. Two reinforcing loops highlight the dynamic of the competition between bus and colectivo. First, the ability to grow demand by serving newly developed areas and providing an overall higher level of service. Secondly, this is reinforced by the continuous "consumption" of the bus ridership and the consequent shrinking of the bus network.

[24] For further information on the field of system dynamics and its applications, see Sterman (2000).

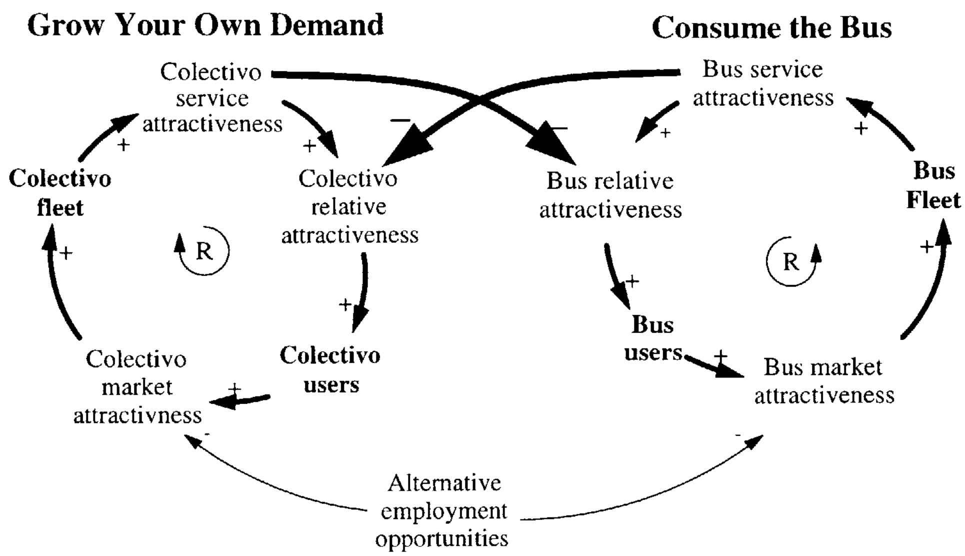

Figure 2-3: The Colectivo-Bus System Dynamics Model[25]

2.1.5 From 1988 to 1994

This period was marked by the politics of deregulation of the transport sector originally planned in the previous administration. The result was even faster growth of the colectivo ridership and fleet mostly at the expense of the Metro, trolleybus, and Ruta-100 whose shares continued a steady decline[26] (see Figure 2-2 and Table 2-1). At the same time, there was a marked shift in travel patterns from the center of Mexico City to the periphery of the region were most of the growth is occurring.[27] This significant change is noted when comparing the results of the 1983 and 1994 home-interview origin-destination survey for Mexico City conducted by INEGI, the national institute of statistics and geography.

The first metropolitan organization, the "Comisión de Transporte del Área Metropolitana" (COTAM) was formed in this period to coordinate plans between the DF and EM. This was the precursor organization to the present-day "Comisión Metropolitana de Transporte y Vialidad" (COMETRAVI), formed in 1994. The

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[25] Developed by Yoshikazu Shimazu, Osama Uehara, and Chris Zegras
[26] Roldán et al. (2000)

governments of the EM, DF, and the federal "Secretaría de Comunicaciones y Transportes" (SCT) currently participate in COMETRAVI.

In 1990 the first Integrated Transportation and Roadway Program (PITV) was signed by authorities in the DF and EM outlining the metropolitan transportation objectives for Mexico City. These included:

1. To reverse the decline of urban transport in the city,
2. To improve the quality of the existing transportation services and the coverage to low-income areas,
3. To satisfy the growing mobility demand, giving priority to public transport over private vehicles, and
4. To help mitigate the air pollution problem.

There was also an effort to control emissions from vehicles with internal combustion engines through the "Programa contra la Contaminación." This program included demand management measures such as "Hoy No Circula" where private vehicles are restricted from operation at least one day per week on a rotating basis. Also included were inspection and maintenance programs, improved gasoline standards, and a program to substitute 20-seat microbuses for two 10-seat combis. At the same time, however, a program to reduce the number of vehicles operating with a colectivo license was cancelled resulting in an oversupply of services due to the larger vehicles (Roldán et al., 2000).

2.1.6 From 1994 to the Late 1990s

In this period, the second version of the PITV (1995-2000) was completed. Some have criticized this document for containing contradictions with implications for both mobility and air quality in the region. For example, there is a stated policy of disfavoring the use of private vehicles in the MCMA because it would lead to greater congestion on the already limited roadways and greater total emissions. However, the plan also calls for

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[27] Cervero (1998)

significant investments in roadway infrastructure to satisfy the increasing demand.[28] In this situation, Mexico City can be characterized as caught in a "vicious cycle" of urban transportation. It is important to consider this complex economic cycle that drives the urban transport dynamic, as shown in Figure 2-4, in order to better understand the challenges confronting Mexico City.

Transportation infrastructure serves as the backbone of any urban area by facilitating the movement of goods and people. It is through transportation that economic growth is enabled. This economic growth, in turn, generates mobility impacts most often manifested through increasing trip rates, rising motorization, shifts towards more rapid travel modes, and growing trip distances.[29] An example of this is the theory proposed by Cervero (1998) that the combined Metro-colectivo system in Mexico City has enabled much of the growth of the urban area since the 1970s.

The increased mobility then produces internal and external economic impacts. The most significant negative "externalities" include congestion, air pollution, and traffic accidents. These effects undermine the effective provision of transportation services and may inhibit economic growth by wasting resources and time, and impairing health. It is at this stage of the urban transport "cycle" where conflicts between mobility and the environment most often emerge. Some form of investment or intervention is needed to reduce transportation's negative impacts and continue enabling economic growth; on the other hand, many interventions are difficult or impossible due to constraints such as air pollution, lack of resources or politics. The dilemma can thus be summarized as how to mitigate or eliminate transportation's negative impacts while allowing it to serve its role in the urban economy. This is particularly relevant for large cities in the developing world, such as Mexico City, where urban growth is most rapid, financial constraints are most pronounced, and externalities (such as air pollution) are most severe.[30]

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[28] Roldán et al. (2000)
[29] Zegras et al. (2000)
[30] Ibid.

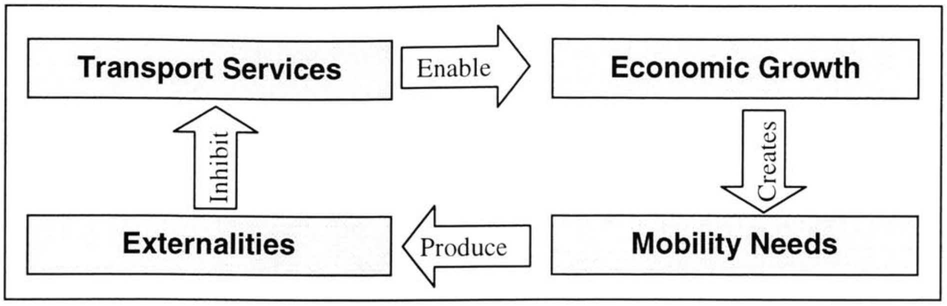

Figure 2-4: Vicious Cycle of Urban Transportation
Adapted from Zegras et al. (2000)

The middle to late 1990s was also marked by reduced government subsidies to public transport and the bankruptcy of Ruta-100 in 1995. Some of the more profitable concessions owned by Ruta-100 were put out to bid by the private bus companies. However, the result was a continued decline in bus mode share and severe service contractions. Already by 1994, the network coverage of colectivo routes was much greater than the Ruta-100 network. Evidence of this can be seen in Figure 2-5 by the density of colectivo routes in the DF and the extent which they penetrated distant and underserved markets in the EM. The disparity grew as the bus ridership and network withered away in the face of more flexible, productive, and aggressive colectivos.

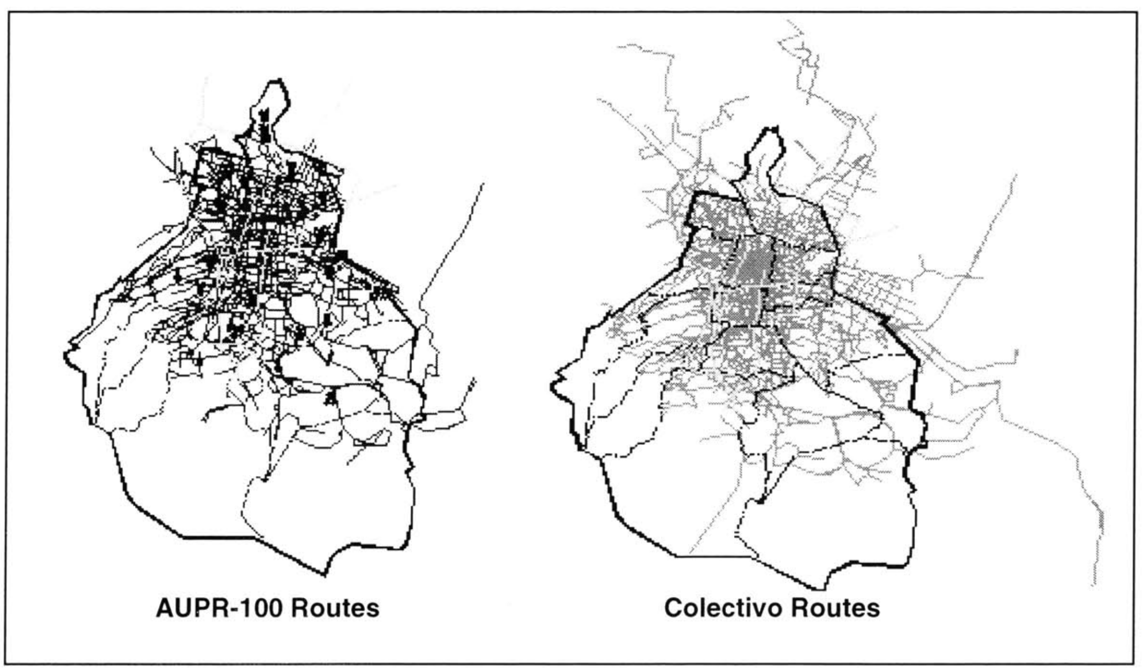

Figure 2-5: Networks of Colectivo and Bus Routes in the DF in 1994

Also of importance in this period was the formation of the "Secretaría de Transportes y Vialidad" (SETRAVI) in 1995. All planning and management functions in the DF government were now under this new organization. The metropolitan organization, COMETRAVI, remained a coordinating agency without tangible powers in the DF and EM.

2.2 The State of Urban Transportation in Mexico City

2.2.1 The Current System

Colectivos continue to dominate the public transportation market in MCMA with about 60% of the passenger mode share since the late 1990s (COMETRAVI, 1999a). They also captured about 59% of all passenger trips in the DF in 1998 (excluding non-motorized modes such as walking and biking), as shown in Figure 2-6. The DF also experienced a decline in taxi, bus, and private automobile modes. The drop in the share of automobiles is difficult to explain and may actually be the result of different accounting methods. It is believed that in absolute terms, the number of auto trips has increased in the last five years, but perhaps at a slower rate than total trips, resulting in a slight mode share decline in the DF. There are currently about 3 million registered private automobiles in the MCMA growing at a rate around 5% annually, or about twice as fast as population growth.[31]

Although the most recent data available are from 1998, all indications are that public transportation mode shares have remained relatively stable into the present. Similarly, the fleet size of road-based public transport vehicles has stabalized after several years of growth in some modes and a decline in others. Figure 2-7 illustrates the evolution of the vehicle fleets for various modes. In the last few years, the largest gains have been in the taxi fleet while the largest losses were in buses due to the collapse of Ruta-100. In the last six years, the former bus system has been replaced by a handful of privately-operated

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[31] Cervero (1998)

bus companies with concession agreements and the RTP ("Red de Transporte Público") bus system operated by the DF. With respect to the colectivos, there has been a incremental substitution of combis or vans for microbuses over the last decade, particularly in the DF. While the sum of colectivo vehicles in the DF has remained relatively stable, their passenger capacity has increased slightly in the last few years.

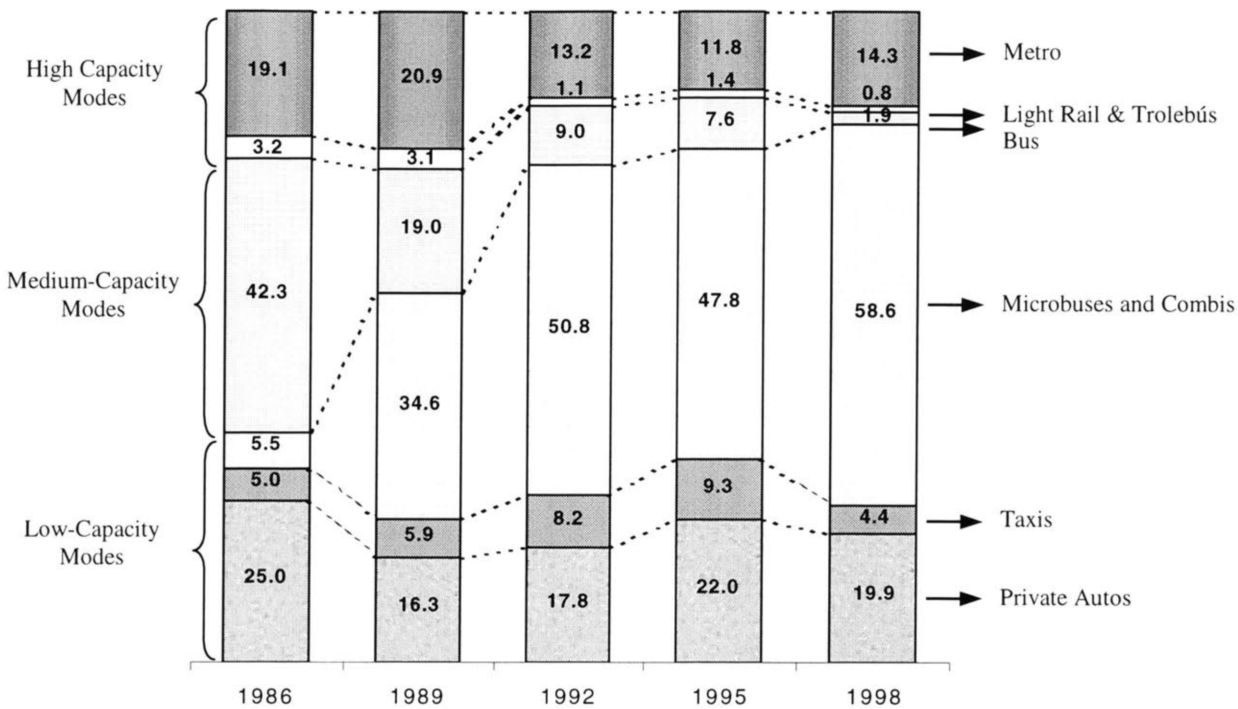

Figure 2-6: Evolution of Mode Shares (%) in the DF, 1986-1998

Source: SETRAVI (1999)

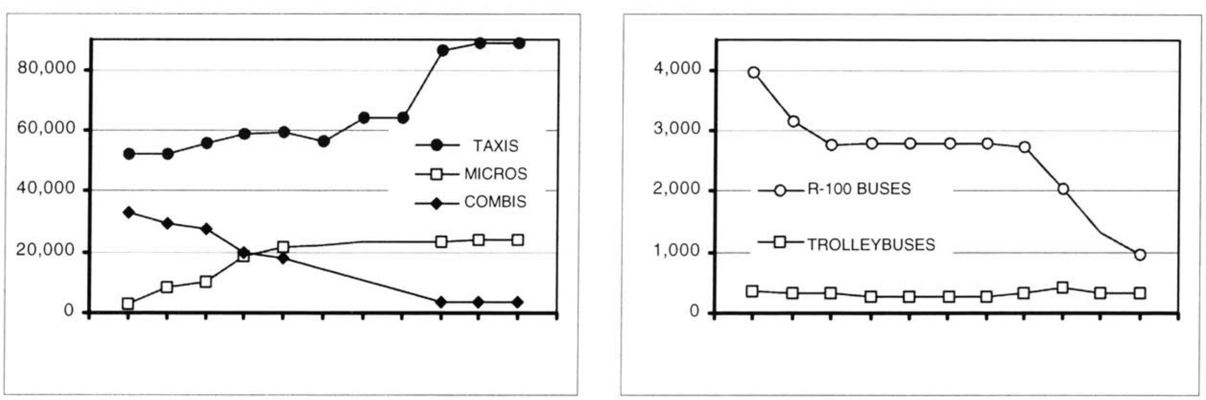

Figure 2-7: Evolution of Road-Based Public Transport Vehicle Fleet in the DF

Source: SETRAVI (1999)

2.2.2 Characteristics of the Colectivo Mode

"Taxis colectivos" is the general term used to describe intermediate-capacity, informal public transportation modes in Mexico City. This includes the spectrum of services from the original shared-ride taxi sedans to the relatively fixed-route microbuses more common in the central areas of Mexico City. Chapter 5 discusses the entire range of transit services in greater detail. A photograph of the ubiquitous colectivo microbus travelling on an urban arterial in downtown Mexico City is shown in Figure 2-8. Note the route sign in the right corner of the front window. These vehicles typically seat 20 to 25 passenger with up to 15 more standing. The vehicle itself is based on the gasoline truck platform and the chasses were produced by several local manufacturers in numerous different styles. The emissions of these vehicles are comparable to a similarly loaded local freight truck of the same vintage. A government-mandated ban on new vehicle production has been in effect since the mid-1990s.[32] Therefore, the average age of the colectivo fleet has increased steadily every year as their road-worthiness declines.

Figure 2-8: The Colectivo (Microbús) of Present-Day Mexico City

[32] Based on a presentation by Florencia Serrania, SETRAVI, on 9 March 2001 at el Colegio de México. It is presumed that new colectivo vehicles were not imported into the MCMA in this period.

The total number of fixed-route colectivos (*taxis colectivos de ruta fija*) in the MCMA in the late 1990s was estimated at over 52,000 with about half in the DF and the other half in the EM (see Table 2-2). This represents about 32% of all concessioned vehicles in the MCMA which include taxis and privately-operated buses. Yet they carry well over half of all trips and passenger-kilometers. This is an indication of their high utilization and productivity. While vans are more prevelant in the EM and better suited for the lower demand, lower densities and unpaved roads found at the periphery of the MCMA, in most of the DF and particularly in the high-demand corridors of the CBD, microbuses are the standard colectivo vehicle.

Table 2-2: Registered Public Transport Vehicles in the MCMA, 1996 – By Mode and Vehicle Type *(Adapted from COMETRAVI, 1999)*

Mode	DF	EM	Federal (SCT)	Total	%
Taxi	85,437	6,061	--	91,498	56.7
Colectivos	26,263	25,915	--	52,178	32.3
Urban/Suburban Buses	--	11,521	6,324	17,845	11.0
Total	111,700	43,497	6,324	161,521	100.0
Percentages (%)	69.2	26.9	3.9		

Type of Vehicle	DF	EM	Federal (SCT)	Total	%
Automobiles (sedans)	85,252	9,272	--	94,524	58.5
Vagoneta (vans)	4,353	15,616	624	20,593	12.7
Microbuses	22,060	7,083	2,325	31,468	19.5
Buses	35	11,526	3,375	14,936	9.2

2.2.3 Key Stakeholders Involved

Stakeholders are individuals or organizations that may not necessarily be the end users or consumers of the services but are vitally concerned with the operations and practices of the transportation enterprise (Sussman, 2000). There are numerous stakeholders in the "colectivo public transportation system" in Mexico City as illustrated in Figure 2-9. The viewpoints of each are described below.

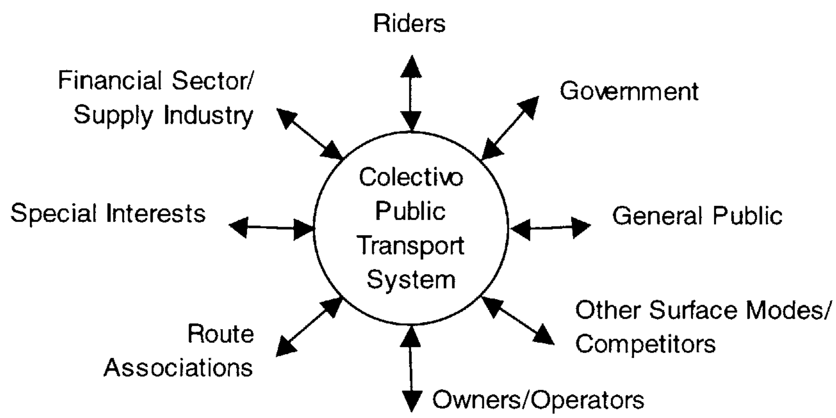

Figure 2-9: Stakeholders in the Current Mexico City Colectivo System

- The vehicle owners are primary stakeholders of the colectivo transportation system. They have directly invested in the vehicles, vehicle registration, and the concession to operate a particular route. The law limits the number of vehicles to three per person but some owners buy additional ones in the names of their spouse or children. With one vehicle, an owner and family can subsist. This is the essence of what the Mexican figure of the "*hombre-camión*" that is characterized by the individualized operation and administration of the vehicle by its owner. Some owners have even mortgaged their homes to purchase their vehicle. According to various government studies, the colectivo business is a highly profitable for the vehicle owners.[33] Most people who enter the business do so with the intent of owning more than one vehicle to increase the returns.[34] Owners may also hire or lease their vehicles to operators for a part of each day. Changes to the current public transportation arrangement will need to ensure the economic vitality of their investment to gain the support of the owners. Most vehicle owners and concession-holders are paying members of route associations which function to protect the interests of its constituents.

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[33] COMETRAVI (1999) v.7

[34] Based on an interview with Julio Figueroa in April 2000. An owner with several vehicles typically does very well—for instance, he is able to own a car and take vacations in the United States.

- Route associations are defined by COMETRAVI (1999) as "civil associations whose constituents are individual concession-holders of specified routes." They provide the on-street regulation of colectivos by controlling the operations and entry and exit of vehicles onto a route or market. In this manner, route associations act as private regulators. They are organizations formed by individual vehicle owners and concession holders. The larger ones possess many corporate elements like a president who represents the association in all official affairs, a treasurer who administers the funds collected from members, and a secretary (COMETRAVI, 1999a). Historically, however, they have also had very informal business practices, some bordering on illegal activity. These organizations wield tremendous power by controlling the development of the route and its operations. They also provide a number of services for its members including a towing service, representation in the case of accidents (e.g. dealing with insurance companies), and issues with fares and the invasion of routes in front of government authorities (Interview with Figueroa, April 2000).

- The chofers or drivers are also key stakeholders of the current colectivo transportation system. The vehicle owner usually drives, manages his hours, maintains his own vehicle, and in many cases hires drivers for a second shift. Most vehicles are operated in two shifts from the early morning to the early afternoon, and another until the end of the night. The labor relations between the vehicle owners and the drivers are usually informal and non-contractual. The drivers usually work six days per week, up to ten hours per day, with very few social benefits or insurance (COMETRAVI, 1999a).

- The dispatchers are those who control the vehicle departures and passenger boardings. In general, they do not have a fixed income and are not members of the route association, but rather rely on tips from the drivers and operators based on the performance of their work.[35] They are common on high-demand routes and during peak hours.

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[35] COMETRAVI (1999) v.7

- The current riders or passengers of the system are also key stakeholders. They make decisions about the level of service, fares, and other factors when choosing to use colectivos. When changes occur to the colectivo system, they are also directly impacted. Potential riders can also have a stake in the colectivo system.

- The general public of the MCMA also has a stake in the state of the road-based public transport because the number and operation of colectivos affects mobility in the region, congestion, quality of life, and perhaps even health.

- The government at various levels in the MCMA provides in most cases the infrastructure, planning, or high-capacity transportation services (e.g. the Metro, light rail, and trolleybuses). It is charged with balancing regulatory, public safety, health, or other social objectives. It also has an interest in maintaining competition between modes to reduce the costs of mobility to the public. For example, preventing and regulating monopolistic practices by colectivos is one of the roles of the government.

- Many special interests and other organizations may be aligned with or against the current colectivo system. The environmental community in government and non-government organizations, for example, has favored tightening colectivo regulations to reduce their impact on congestion and emissions.

- Financial and consulting institutions providing support for transportation projects such as bilateral or multilateral development banks, insurance firms, equipment suppliers, and national banks also have a stake in the colectivo system. For instance, in the recent past Banobras (the Mexican development bank) offered loan credits to colectivo drivers to purchase microbuses with a 30% down payment and 36 monthly installments of $3,000 pesos.[36] More recently, SETRAVI has tried to encourage the replacement of the oldest colectivos with new buses by developing a financing

[36] Interview by Prof. Ralph Gakenheimer with Julio Figueroa, April 2000

scheme where 15% of the vehicle cost would be subsidized. Mexican banks, however, have balked at providing loans calling the scheme risky.[37] Also included in this group are international agencies, consulting firms, and academic or research institutions.

- The vehicle supply and resale industry are stakeholders in the current system. Truck and automobile parts and manufacturing are big businesses in Mexico. The colectivo mode comprises tens of thousands of vehicles that need to be maintained. Also of financial importance to the colectivo sector is the resale of old vehicles. For instance, about 70% of the DF's old transit vehicles, typically 15 to 20 years old, end up in the EM.

- Other road-based public transport modes, particularly competitors to the colectivos, are also stakeholders. The colectivo owners and drivers view both taxis and buses as their competitors. There are about 100,000 taxis in the MCMA, most of them in the DF. All surface modes, whether competitors or not, are affected by congestion caused by the colectivos.

2.2.4 Organization of Service Providers

The origin of the modern-day colectivos of Mexico City were shared-ride taxis known as *peseros,* named after their original fare of one peso. The owners of these private vehicles offered transport services with flexible routes and schedules— in sum, a fare and level of service between the bus and taxi of the time. The peseros captured a "niche" public transport market serving a particular segment of the population. The flexibility of this "informal" service and the characteristics of the vehicles allowed it to capture about 3% of daily demand in the early 1970s. The majority of pesero owners of the time became members of three pre-existing organizations: (1) the Confederación Nacional de Organizaciones Populares (CNOP), (2) the Confederación Revolucionaria de Obreros y Campesinos (CROC), and (3) the Confederación de Trabajadores de México (CTM). This

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[37] *El Universal* newspaper article, "No respaldan bancos el cambio de microbuses", 30 April 2001.

development helped shape the organizational structure of the colectivo organizations that is apparent today.

Despite the core of the colectivo system being based on the individual "man-truck" unit, key decisions about route development and operations are made by the directorate of route organizations. The larger organizations frequently have several full-time officers and committees formed to determine operating policies, dispatch order of the vehicles, assignment of turns to operators, and market research into extending routes or serving new areas. As a result, routes are modified and extended very often and most operate differently than the conditions spelled out in the original concession agreements. A large, high-demand route may also have numerous branches (*ramal*) and derivatives (*derivación*) as shown in Figure 2-10. Each sub-route typically has a delegate in the directorate. Figure 2-10 also illustrates the labor hierarchy within a route association. The concession-holder and vehicle owner is the official member of the organization but may have drivers and the dispatchers working below him.

Other functions of route associations include securing authorization for branch routes, manage the operations of vehicles along the route, assist owner-members in obtaining loans for vehicles, help settle accident claims, and present a common front for collective bargaining with government authorities.[38] Some associations have also acted as cartels protecting their market from "piratas" or pirate colectivos who may try to invade a route by violence. In many ways, these 8,000 or so pirate vehicles are the real informal sector because most of them unlicensed and completely unregulated. In the late 1980's, route associations also organized road blockages to coerce the government into agreeing to their demands. These organizations are also associated with the black and counterfeit market for colectivo licenses. The amount of power wielded by these organizations appears to be directly related to their size.[39] COMETRAVI (1999) concludes that history has shown that a handful of people heading these organizations make decision that are not always in line with providing the best service but ensuring their own interests.

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[38] Cervero (1998)
[39] Ibid.

Presently, the vast majority of all colectivo concession-holders are represented by route associations which, in turn, are grouped under 21 "umbrella" organizations in the DF. These umbrella organizations essentially act as a lobbying body for both their constituent route associations and the industry in general. Cervero (1998) characterizes the hierarchical organizational structure as the evolutionary response of the paratransit sector to the need for self-regulation and administration.

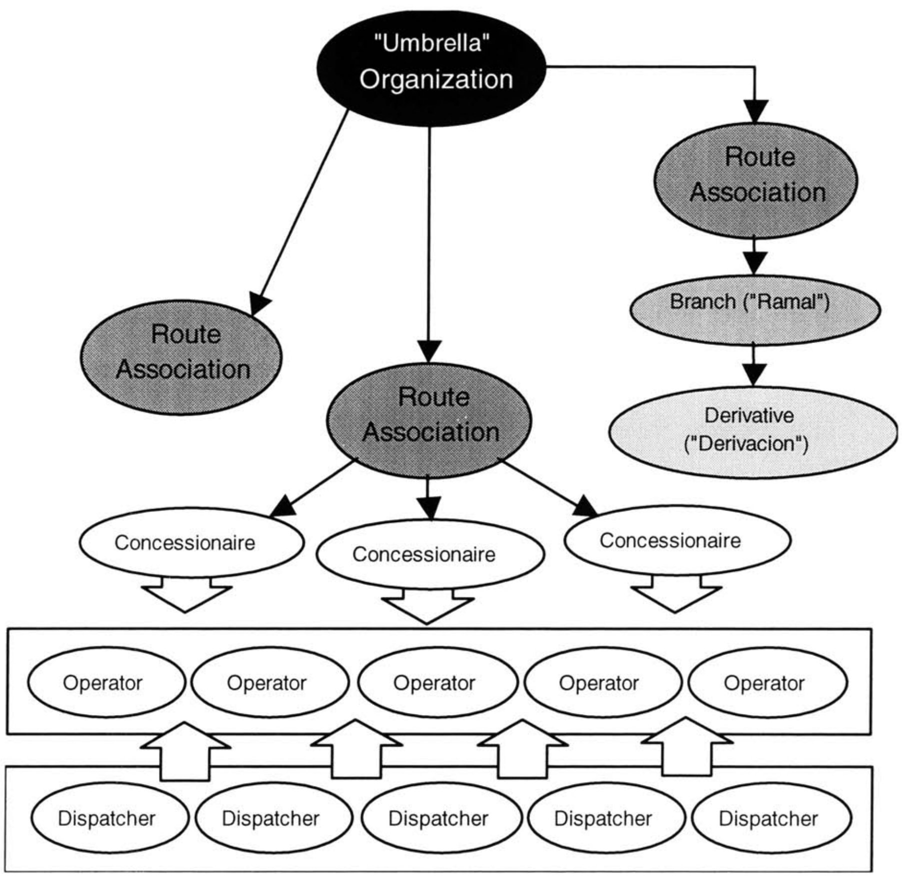

Figure 2-10: Colectivo Organizational Structure

Source: COMETRAVI, (1999) v.7

In the DF, there are over 110 registered routes and more than 900 branches or route derivatives operated by about 27,000 vehicles.[40] Half of all the branch lines and over half of all vehicles are concentrated in 17 routes with the highest demand. In the urbanized regions of the EM, 94 firms and 172 associations operate under 11 umbrella organizations.[41] Nearly all of these routes originating in the EM end at Metro terminal stations just across the DF side of the border. Figure 2-11 illustrate the major colectivo routes (left) and RTP routes (right) in the DF.

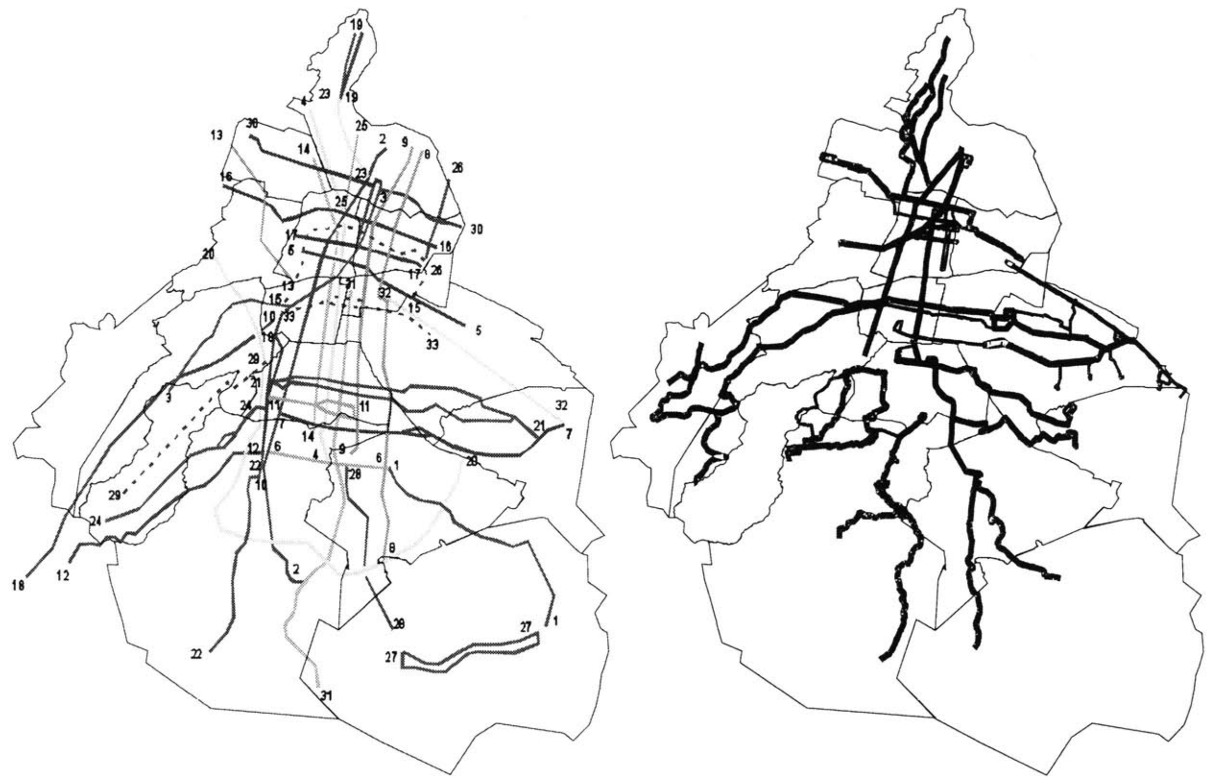

Figure 2-11: Major Colectivo and RTP Routes in the DF
Source: Presentation by Florencia Serrania, SETRAVI, March 2001

2.3 The Dynamics of Colectivo Growth

In order to understand the astonishing growth of the colectivo mode over the past two decades, it is important to understand the nature of informal transit. In the beginning, colectivos were an informal but tolerated sector of the economy whose characteristics and operations were closer to the conventional taxi service. Their reason for providing such services at the time was a need and the market potential for inexpensive, shared-ride taxis

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[40] Presentation by Florencia Serrania, SETRAVI, at El Colegio de México on 9 March 2001.
[41] COMETRAVI (1999) v.7

providing a higher level of service than buses. The market was relatively small because it was constrained by the operations of a large government-supported bus network.

After several years and formal recognition from the government, the colectivo sector began to formalize its operations and incorporate a hierarchical organizational structure that suited its geographic network and labor requirements. Several external factors perhaps had an even greater influence over its growth. The comprehensive study published by COMETRAVI (1999) identifies the three most important external factors to the growth of the colectivo sector. First, the construction of the "*ejes viales*" in the late 1970s facilitated the formation of routes, reduced congestion, and allowed for on-street stopping and connections to the Metro and bus networks. The improvement of major roadways also allowed the colectivos to widen their average operating speed advantage over buses. Second, the abrupt expropriation of the private bus service under the ACM in 1981 and the creation of Ruta-100 allowed colectivos to fill gaps in service as the new bus organization was being reorganized. Ruta-100 resulted in a market failure that opened the door for the substitution of conventional transit services by the more adaptive colectivo sector. Finally, changes in vehicle capacity over time may also have played a significant role in the success of the colectivo sector by allowing for higher revenues and the transition of colectivos to high-demand, semi-fixed routes. In sum, the incremental substitution of the early sedans (capacity of about five) for van (capacity of about ten), and eventually for microbuses while maintaining a speed and maneuverability advantage over the bus enabled colectivo growth.

From this synopsis, several interesting factors related to the growth of informal transit stand out. First, where there is a profit potential from either inefficient formal providers or high demand, one can expect the appearance of the informal sector undercutting the prices of the established sector. A low level of service from the established transit sector can also drive the growth of alternative services. This was clearly the case in the beginning as colectivos benefited from supplementing or exploiting the weaknesses of the formal bus system.

A conceptual framework is presented in Figure 2-12 representing the dynamics of colectivo growth in road-based public transport. Five factors were identified to both affect and be affected by colectivo growth: (1) level of service, (2) congestion, (3) regulation enforcement, (4) profitability, (5) urban sprawl. As the level of service improves, in the form of travel time, service frequency, or accessibility to the network, colectivo ridership increases. Second, as congestion increases from the growth of traffic relative to the available infrastructure, colectivo growth may be constrained. Third, a lack of regulation and enforcement also encourages growth. Fourth, higher profitability, driven by increased passenger demand, also stimulates colectivo fleet growth. Finally, population growth and new development, including irregular settlement on the periphery of the region, encourage growth of the colectivo network. The model described in Chapter 3 will test three of these factors, namely level of service, congestion, and profitability, at the transportation corridor level.

One should also consider the externalities involved in the dynamics of growth. As the fleet of vehicles and quantity of service is increased, the increased congestion has a negative impact on emissions and level of service. In Mexico City, some believe the explosive growth and undisciplined operations of the colectivo fleet have caused much of the roadway congestion. However, congestion and travel time are also been affected by the growth of private vehicle use driven by increasing incomes. Although not included in this thesis, other significant externalities such as noise pollution may also be byproducts of fleet growth. The potential methods of constraining the negative impacts of colectivo fleet growth include regulation, technology measures, and increased efficiencies through integration and coordination. Several of these measures are discussed in later chapters.

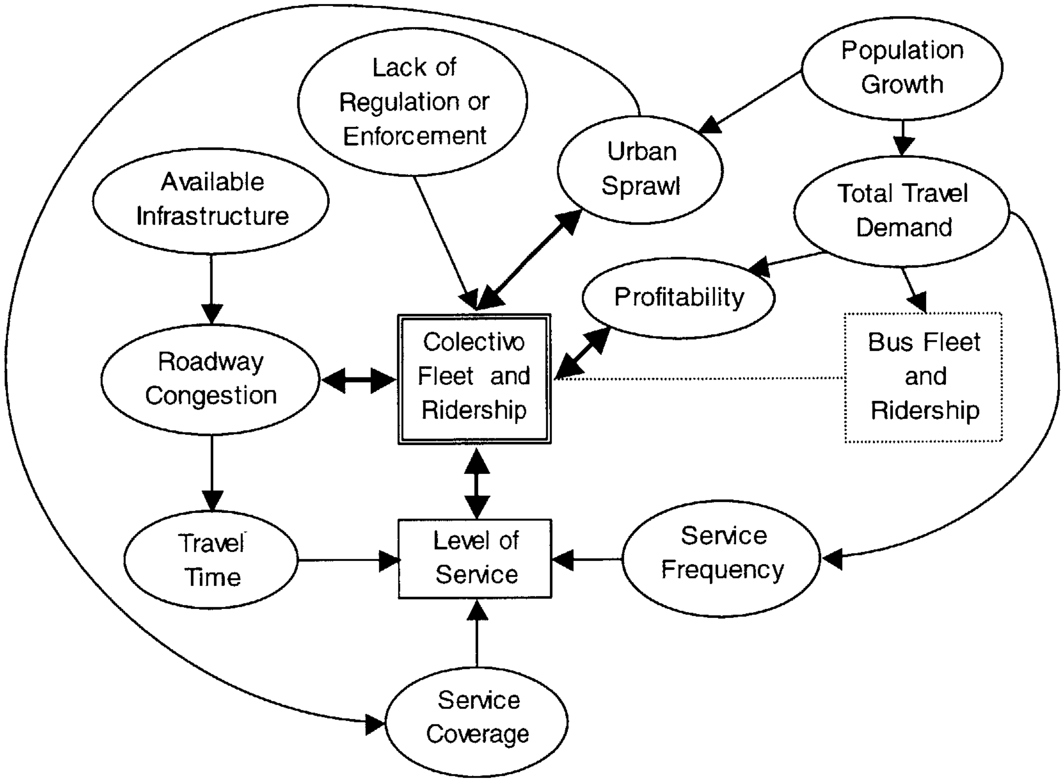

Figure 2-12: Dynamics of Colectivo Fleet and Ridership Growth

2.4 Comparison of Modes and Emissions

In comparing the air pollution contributions of different modes, ideally one should consider the emissions per vehicle kilometer traveled (VKT). Since this data is not available and difficult to accurately estimate, Zegras et al. (2000) analyze the relative contribution of the different modes to air pollution using two alternative indicators. First, an index based on the relative contribution of each mode to total air pollution in the MCMA using the 1996 INE emissions inventory and the MCMA vehicle fleet in 1994 from COMETRAVI (1999) is presented in Figure 2-13. It shows that according to this relative index of pollution per vehicle, buses are the largest relative contributors of both PM_{10} and NOx. Trucks and taxis are also high contributors of CO and NOx emissions. However, this measure is highly dependent on the intensity of vehicle use (i.e., VKT). Thus, the effects of heavily used vehicles may be overstated.

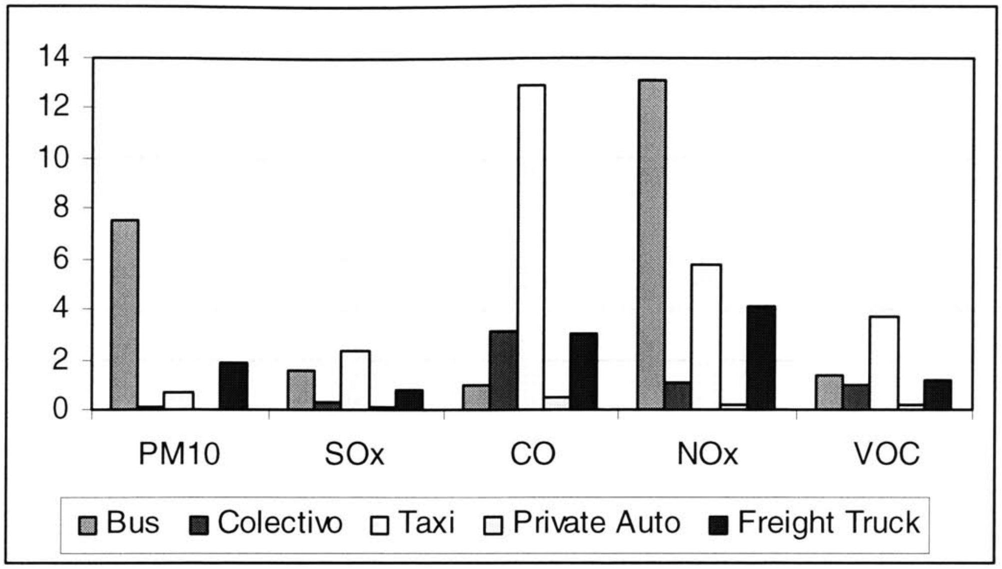

Figure 2-13: Index of Pollutant Contribution per Vehicle Type in the MCMA
Sources: Zegras et al. (2000) and COMETRAVI (1999) v.6

The second index developed by Zegras et al. (1998) was applied only for the passenger modes. Figure 2-14 shows the relative index of emissions with respect to the total number of daily passenger trips by mode. The index is based on the relative contribution by mode of total air pollution in the MCMA using the 1996 INE emissions inventory and the number of passenger trips in the MCMA by mode based on the 1994 MCMA origin-destination study (as reported in COMETRAVI (1999) v.6). This relative measure shows that taxis are the largest contributors by passenger trips for all pollutants considered. The high index for taxis is likely due to their relatively low occupancy rates from excessive circulation without passengers. The private automobile is a close second to the taxi for all pollutants also suggesting a low occupancy rate. On the other hand, road-based public transport modes, namely buses and colectivos, are relatively low contributors to emissions because of their high occupancy rates.

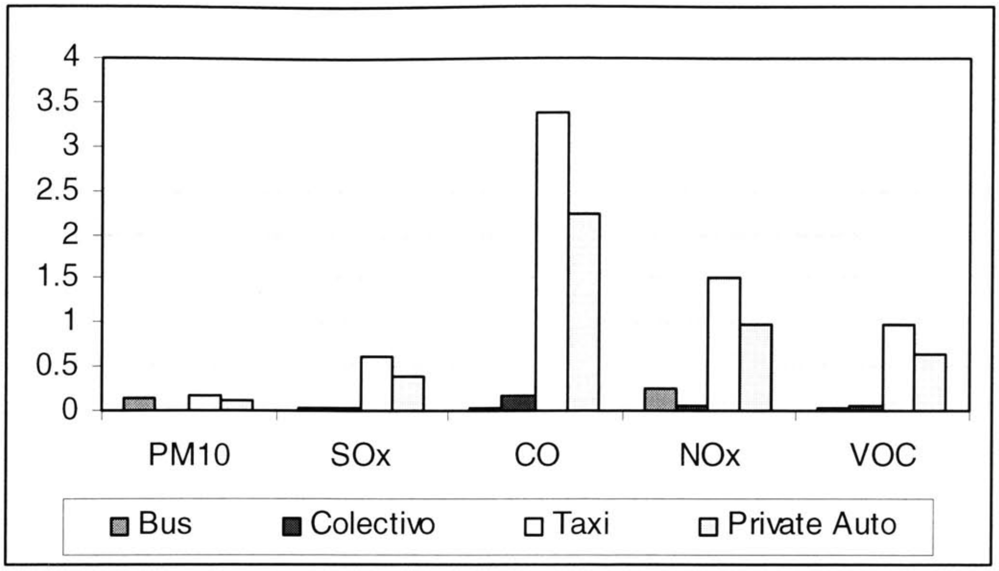

Figure 2-14: Index of Pollutant Contribution per Passenger Trip in the MCMA
Sources: Zegras et al. (2000) and COMETRAVI (1999) v.6, pp. 3.

2.5 The Political Environment

2.5.1 Emissions and Air Quality

Good air quality is not simply a luxury but a necessity for unimpaired human activity. Developed world countries typically have a greater ability to allocate resources to this problem where countries in the developing world may not. As a result, urban air quality will likely continue to improve in the developed world while it degrades significantly in the developing world over the next few decades.

Motor vehicle transportation has contributed significantly in making Mexico City one of the most polluted cities in the world. The government has invested at least $5 billion over the past decade in an effort to clean the air in Mexico City.[42] Some outdated diesel buses have been replaced, a city oil refinery has been closed down, and some of the hills near the city have been reforested. Nevertheless, the levels of ozone and other pollutants remain high compared to international standards.[43]

[42] ABC News (1999)
[43] EIA (1999)

Mexico began requiring cars with emissions controls in 1991 to mitigate growing concerns about air pollution. The country has also established legislation on emissions controls for taxis, trucks, microbuses, and private cars. The state-owned oil company, Pemex, has replaced the lower-quality gasoline ("Nova") with a higher-octane unleaded gasoline ("Magna Sin"), and replaced the high-sulfur diesel with a new fuel containing about 0.05% sulfur. Those measures are expected to help curb air pollution somewhat, but increasing levels of car ownership and rising trade and highway traffic with Central America and the United States suggest that air pollution will remain a problem for the country's urban areas.

2.5.2 Policy Challenges

Some of the most pressing urban transportation problems today– traffic congestion, air pollution, private automobile dependency, inefficiency and inaccessibility of public service– require a wide spectrum of approaches to achieve meaningful improvements. The automobile will likely continue to dominate the mobility market in developed countries because it is best suited to serve contemporary travel patterns– journeys from dispersed points to dispersed points such as suburb-to-suburb, multi-leg trip chains, spontaneous and irregular travel demand. The developing economies of Latin America are progressing on this very same path, but at differing rates. Vehicle ownership is lower in Mexico than in the other countries of North America, estimated at 148 cars per thousand persons, but the levels of motorization are increasing fast. The transportation infrastructure is also less developed. Only 37 percent of Mexico's roads are paved, compared with around 61 percent in the United States. Mexico has about 55,000 miles of paved roads and nearly 2,000 miles of highways.[44]

The numerous challenges of transportation and air quality policy were recently summarized in a presentation by Dr. Arnold Howitt[45], executive director of the Taubman Center for State and Local Government. First and foremost, there is a problem of scope

[44] Ibid.
[45] Presentation given by Dr. Arnold Howitt, Harvard University's Kennedy School of Government, at MIT

and diversity. National policies must be appropriately applied to different locales as a function of geography, meteorology, economic and social aspects, cultural values, and existing transport systems. Second, the geographic span of transportation systems and air quality problems typically do not correspond to the political boundaries of single unit of government. Third, scientific uncertainty about the physical system and empirical uncertainty from limited data collection also presents a challenge. An example is the debate over the health effects of PM-2.5.

A recent article also demonstrates a financing challenge to the problems of transportation in Mexico City. SETRAVI plans to support concessionaires with 15% of the value of a new bus, enough to be used as a down payment. However, no private bank is willing to participate in the financing of this recently announced program to replace microbuses manufactured in 1989 or before with new full-size buses.[46] In essence, the banks feel the investment is too risky because the concessionaires may not be able to pay back loans as a result of the vigorous competition for passengers by the colectivos.

2.5.3 Political Perspectives on the Colectivo

The political debate in Mexico City is characterized by the dilemma of the colectivo as a good alternative to private vehicles but a bad substitute for a more efficient system of high-capacity transit vehicles. Many government officials in Mexico City strongly favor a policy of promoting high-capacity modes, namely conventional buses and the Metro, because they view colectivos as fundamentally a low to medium-capacity mode, difficult to control and inspect, and producing high negative externalities. Yet, the colectivo sector wields tremendous political power because of its size and role in enabling economic activity in the MCMA. It would be difficult to name another sector of the economy that has the ability to paralyze the entire city. Further, the residents of Mexico City in effect are "voting with their feet" by giving colectivos a dominant market share.

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on 2 May 2001.

[46] *El Universal* newspaper article, "No Respaldan Bancos el Cambio de Microbuses", 30 April 2001.

Colectivos also receive much criticism for their operations. In the crowded urban areas it is common for colectivos to be a large fraction of the street traffic. Colectivos are anecdotally known for unsafe or chaotic driving patterns driven by on-street competition for riders and for blocking roadways while loading and unloading passengers. On the other hand, Cervero (1998) characterizes their driving behavior as no more aggressive than other motorists and better than in most other developing world cities with a thriving paratransit sector. He attributes their discipline to the control of route association, which ease some of the competition for customors and, in fact, promote camaraderie among operators of the same organization.

Additionally, the disdain of the automobile-driving public and government officials for the "contaminating colectivo" may actually be based on subjective reasoning rather than fact. As shown in Section 2.4, when considering emissions per passenger trip, colectivos are one of the most efficient road-based modes. The reason for such opinions may actually be the congestion and aggravation colectivos cause to automobile drivers on arterials during peak hours. Most private vehicle users are middle and high-income people with considerable political influence and power. The reality is that colectivos provide a high frequency and relatively fast service that people want. Some may argue that this is the case because of a lack of a real alternative rather than by choice. In any case, assuming that people will use a slower or lower frequency service without offsetting benefits is not reasonable.

The characterization of the colectivo as either a low-capacity transit mode or an intermediate-capacity transportation mode may also be problematic. The former suggests that colectivos absorb many trips which otherwise would be made on private modes. The latter implies that colectivos are just above private vehicles in the wide spectrum of transportation modes. Most studies agree that the average colectivo rider is a working person of the lower income group without a private vehicle at their disposal. However, with increasing per capita incomes, these same people are likely to switch to private modes as soon as their incomes allow it.

Finally, as other informal transit systems around the world, the colectivo system in Mexico City operates without direct public subsidies and absorbs thousands of people in its labor force. It has given a vast number of relatively unskilled migrants and the unemployed an opportunity to be an integral part of the urban economy. It is typical for a dispatcher or driver to work up to become a vehicle owner after a few years. The political and economic implications of this arrangement cannot be overlooked.

In summary, two popular opinions seem to exist in Mexico City concerning the colectivos. One is of most government officials and automobile users favoring restrictions on the colectivo citing their negative externalities. The other, more subdued and indirect, is manifested by the travel behavior of the masses. The latter, of course, is subject to the degree to which public transportation users are captive to the colectivo mode. At this stage, the policy debate over the benefits and costs of colectivos may be enhanced by quantitative economic analysis. To this end, Chapter 3 will focus on modeling and analyzing the mobility and emission tradeoffs of various transportation measures along a corridor.

Chapter 3. Modeling Road-Based Public Transport

3.1 Introduction and Motivation

The primary reason for modeling transportation-related emissions is that mobile sources typically account for more than half of all airborne pollutants in most large cities. For instance, transportation accounted for about 75% of emissions in the Mexico City Metropolitan Area in 1994.[47] The most recent emissions inventory produced by the metropolitan commission for the environment in the MCMA, known as CAM, estimated that about 80% of emissions by weight were attributable to mobile sources in 1998 (CAM, 2000). However, the contribution of the transportation sector to total emissions in the MCMA varies greatly by type of pollutant, as described in Chapter 1.

Private vehicles are by far the largest contributors to these estimates. Cars and pick-ups accounted for 5% of PM_{10}, 14% of SOx, 55% of CO, 22% of NOx, and 18% of VOCs of all emissions in the MCMA according to the 1998 CAM inventory. For comparison, buses, taxis and colectivos combined accounted for 6% of PM_{10}, 5% of SO_X, 21% of CO, 12% of NO_X, and 7% of VOCs of all emissions in 1998 while carrying three times as many passenger trips. However, public transport is a highly visible sector subject to public scrutiny and regulation. Theoretically, it is also more manageable because there are fewer vehicles compared to private modes and, in principle, has the potential to absorb or divert growth in private vehicle use.

A recent presentation by Claudia Sheinbaum, current head of the environmental secretariat of the DF, reflected on some of the general trend concerning air pollution in Mexico City.[48] First, Mexico City has seen significant reductions in CO_2 and CO emissions in the last decade. However, ozone (O_3) and PM continue to be at high levels and SOx may increase because of recent increases in the cost of natural gas. Most

[47] COMETRAVI (1999), v.1

scientific observations agree that the Valley of Mexico City is a NOx-constrained airshed, meaning that reducing NOx emissions may be the most effective method of controlling photochemical smog in the form of ozone.[49]

In an effort to support the second phase of the Mexico City Project[50] with quantitative analysis, this chapter describes a modeling method to quantify the expected mobility and emissions impacts of proposed road-based public transport options. There are numerous types of models that vary by level of aggregation (i.e., from microscopic to macroscopic), method of calculation (i.e., discrete or continuous), and treatment of external factors (i.e., deterministic or stochastic). As part of this research, a deterministic equilibrium model was developed that balances public transportation supply and demand at the corridor level. It operates between a macroscopic sector-wide model and the microscopic driver behavior model. Mindful of the tradeoffs between "reality in representation and ease in generating solutions,"[51] this corridor model is believed to strike a reasonable balance between tractability and realism.

It is also important to note that all "models" are wrong because they are a simplification of the real world.[52] Nonetheless, they can be extremely useful in "getting the sign right" or ascertaining the general trend. In complex systems, many measures prove to be double-edged with time, meaning the intended consequences are often accompanied by unintended ones. For instance, the Mexico City "No Drive Day", known as "Hoy No Circula", indirectly encouraged the purchase of additional vehicles (for those who could afford it) to circumvent the driving restriction at least one day per week. Some of these additional vehicles were newer and less polluting, but most were older and cheaper, and undoubtedly resulted in an increase the total vehicle fleet although the effect on total vehicle kilometers traveled may not have been significant.

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[48] Presentation given on March 8, 2001 at the MIT-IPURAGP Mexico Workshop, El Colégio de México.
[49] Molina et al. (2000)
[50] Refers to the MIT Integrated Program on Urban, Regional and Global Air Pollution: Mexico City Case Study
[51] Sussman (2000)

Models can be an important tool in understanding how unintended consequences can occur and how they can be avoided. Models can also quantify the impact of proposed strategies. Although, the specific figures may be held in low confidence because of a lack of data or understanding, the overall trends can be helpful in evaluating trade-offs, as those that exist between mobility and air quality. Importantly, the relative differences in the effects of strategies can be estimated.

3.2 Transportation Planning and Emissions Modeling

The conventional urban transportation planning process includes a four-step method. Input data from inventories or forecasts are used in a trip generation step that predicts the number of trips produced and attracted by zone. The matching of origins and destination is then performed during a trip distribution step. A mode choice step predicts the split between available modes. Finally, a trip assignment step allocates the resulting trips onto a network. The system output, therefore, is information about the traffic volumes, speeds, and mix of vehicles and modes on the links of a network. This traditional method, however, has been criticized for lacking adequate feedback from the output to input in a simultaneous and iterative fashion as occurs in reality.

The system outputs from transportation planning models can be used to predict vehicle emissions in a specified area network. Emissions modeling in the developed world has stemmed from decades of legislation and public concern over urban air pollution. In the United States, legislation such as NEPA (National Environmental Policy Act of 1969), CAA (Clean Air Act of 1970), and CAAA (Clean Air Act Amendment of 1990) engaged cities and regions in transportation modeling in order to predict emissions and form mitigation plans. For instance, the CAAA mandated that metropolitan areas in non-attainment for ozone and carbon monoxide reduce vehicle miles traveled (VMT) and congestion. In addition, it gave the U.S. Environmental Protection Agency (EPA) power to withhold federal highway funds, and to impose a compliance plan or a road-building moratorium.

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[52] Sussman (2000)

There are numerous components of motor vehicle emissions. Exhaust or "tailpipe" emissions, in the form of NOx, CO, PM, VOC, and SOx, is usually the largest share of vehicle emissions.[53] However, evaporative emissions (running losses and "hot soak" emissions) or refueling losses, primarily in the form of vaporized combustion fuel, can be significant as well. Figure 3-1 attributes the components of total emissions from mobile sources to several factors in the life of a vehicle. With the possible exception of NOx, the emissions from driving a vehicle in idealized road conditions are a small share of all emissions. Vehicle degradation with time and use, real world driving behavior, and malfunctions are all very important components and perhaps even more significant in the developing world. This highlights the role of traffic enforcement and inspection and maintenance programs in an overall emissions reduction plan.

Figure 3-1: Components of Total Emissions of Key Pollutants from Mobile Sources

	CO	**VOC**	**NOx**
New Vehicles in Test Cycle	10%	12%	26%
Vehicle Aging	22	10	28
Real World Driving	42	18	37
Malfunction	26	27	9
Evaporative	--	33	--
Total	**100%**	**100%**	**100%**

Source: Heywood et al. (2000)

The rate of emissions depends on a variety of factors including vehicle age, type, maintenance, driving habits, fuel quality, and ambient air temperatures. One of the most widely used emissions models in the world, MOBILE, was created by the U.S. EPA. MOBILE version 5 was applied to the Mexico City fleet of vehicles in COMETRAVI (1999). The necessary user inputs to the MOBILE model include gasoline volatility class (affecting the rate of evaporative emissions), calendar year of vehicles, average speed, operating mode, inspection and maintenance parameters, emissions control technologies, vehicle load factors, ambient air temperatures, and altitude. Additional optional inputs include vehicle age distribution, regional inspection and maintenance program, estimated

[53] U.S. EPA (1994)

levels of tampering with emissions control equipment, emissions from refueling, and the presence of reformulated or oxygenated fuels (i.e., containing additives such as ethanol or MBTE).[54]

The outputs of MOBILE are exhaust emission factors for VOC, CO, and NOx and evaporative emissions of VOC. Exhaust emissions occur along transportation links and are highest during peak vehicle operating hours. These factors are typically measured in grams per distance traveled.[55] Evaporative emissions are measured in grams per event and then converted to grams per distance traveled. The emissions rates are specific to several different vehicle types. For the purposes of this study, three types were considered; light-duty gasoline vehicles (LDGV) including most private automobiles and taxis, light duty gasoline trucks (LDGT) which includes most colectivos, and heavy duty diesel trucks (HDDT) including most buses and trucks.

3.3 The Corridor Model

3.3.1 Background

Corridor planning was first practiced in the 1960s in the United States. It principally focused on improving the vehicle carrying capacity of major roadways. A corridor connects two large centers of trip origin or attraction, such as the central business district, a Metro terminal station, or university campus. It is composed of one or more major roadways that form a continuous route. Corridor planning and modeling is generally regarded as a good approach for evaluating measures in the short to medium-term. It is also a tool in the practice of transportation system management (TSM) where the aim is to maximize the efficiency of the existing system.[56]

There are different approaches to modeling transportation services, roadway conditions, and environmental impact. This thesis describes a corridor model that simulates the characteristics of major roadways served by parallel bus and colectivo routes in Mexico

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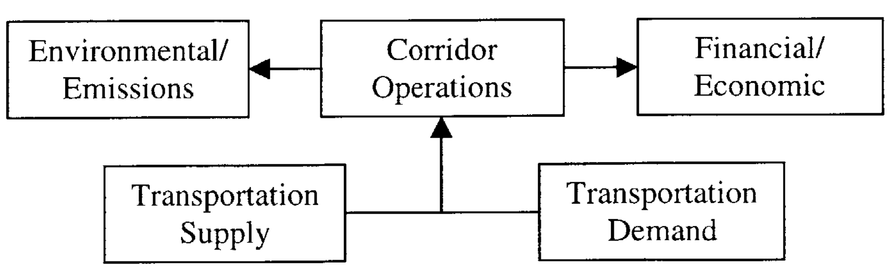
[54] Zegras et al. (1995)
[55] U.S. EPA (1993) as cited in Zegras et al. (1995)

City. Therefore, it requires a relatively high level of data and detail concerning the passenger modes shares, mix of traffic, and total demand. An important simplification is that the model does not consider the corridor as part of a larger network. Therefore, only the trip generation and mode choice steps are performed, but in an iterative manner to approximate actual trip-making patterns. This model is:

- An equilibrium model that balances the supply and demand of road-based public transportation services to understand competition between modes;
- A simple, spreadsheet-based (Microsoft Excel) tool that can be used for estimating costs and benefits of various options;
- A modular tool that can be improved incrementally with better data and methods;
- Most importantly, this model is a tool to demonstrate the tradeoffs between mobility and emissions. Its application is subject to the quality and limitations of the data used to develop it. As such, the numerical solutions presented here should not be used directly. However, the sign and relative strength of the results indicate the most likely impact of various strategies on mobility and emissions.

Figure 3-2 is the corridor model framework. The simultaneous balancing of supply and demand for transportation services influences the operations of the corridor. This includes the mix of modes, travel speeds, and passenger mode shares. Together with corridor characteristics, these can be used to calculate the impact on the financial operations of public transportation vehicles and the emissions of all vehicles along the corridor.

Figure 3-2: Corridor Model Framework



[56] Zegras et al. (1995)

The essence of the corridor model inputs and outputs are described in Figure 3-3. Corridor parameters, vehicle counts, and passenger mode shares are used to calculate passenger trip costs, delay times, emissions, and the redistribution of costs and benefits between the bus and colectivo.

Figure 3-3: Key Model Inputs and Outputs

- Corridor Parameters (e.g. length, capacity, peak/off-peak factors)
- Vehicle Mode Share and Peak Hour Vehicle Count on Corridor
- Passenger Mode Split

- Passenger Trip Costs (wait time + travel time + fare)
- Total Passenger Delay Time
- Total Emissions by Mode and Pollutant
- Impact on Bus and Colectivo Profits

3.3.2 Major Assumptions

Demand:

In this analysis, the total demand in passenger-trips along the corridor is assumed to be fixed in the short-run and known *a priori*. Of course, demand can increase in the longer-term with economic and demographic growth. The corridor model is able to adapt to changes in total demand and simulate various levels of congestion. Increases in total demand can also be induced from the expansion of roads and services. However, the model does not consider this phenomenon.

Capacity:

Capacity is a complex, multi-dimensional system characteristic affected by infrastructure, vehicles, technology, labor, institutional factors, operating policy, and external factors.[57] In other words, network capacity is not just the sum of all the vehicles or the sum of all infrastructure capacities in the transportation system. This suggests that there are many ways to address capacity shortfalls without building more highways, subway lines, or

[57] Sussman (2000)

adding buses. Existing infrastructure can be used more efficiently by encouraging the use of vehicles with higher capacity, such as exclusive bus lanes, or by restricting the use of low-capacity vehicles on other lanes. Along the same lines, the existing vehicles can also be used more efficiently by increasing their occupancy.

The corridor model uses the concept of a volume to capacity ratio (V/C) to estimate the level of congestion on a roadway. The total capacity of a corridor is assumed a function of the number of lanes and the ability of each lane to serve a certain number of vehicles per hour. Figure 3-4 is an illustration of an example corridor. According to Highway Capacity Manual standards and COMETRAVI (1999), a reasonable figure for an arterial lane is 750 equivalent vehicles per hour. Since the various modes tested have different physical characteristics (such as size or acceleration) and operations, they may impact roadway congestion differently. To account for this, a vehicle equivalency was developed based on procedures from the Highway Capacity Manual. A private automobile (passenger capacity of 5) or taxi (passenger capacity of 3 plus the driver) is assumed to be one equivalent vehicle, while a bus (passenger capacity of 70) or truck is two equivalent vehicles. The colectivo equivalency is linearly extrapolated between one and two equivalent vehicles depending on the vehicle capacity. For example, the vehicle equivalency of a colectivo microbus with a seated and standing capacity of 35 passengers is calculated by adding 1 and 35/70, yielding 1.5 equivalent vehicles.

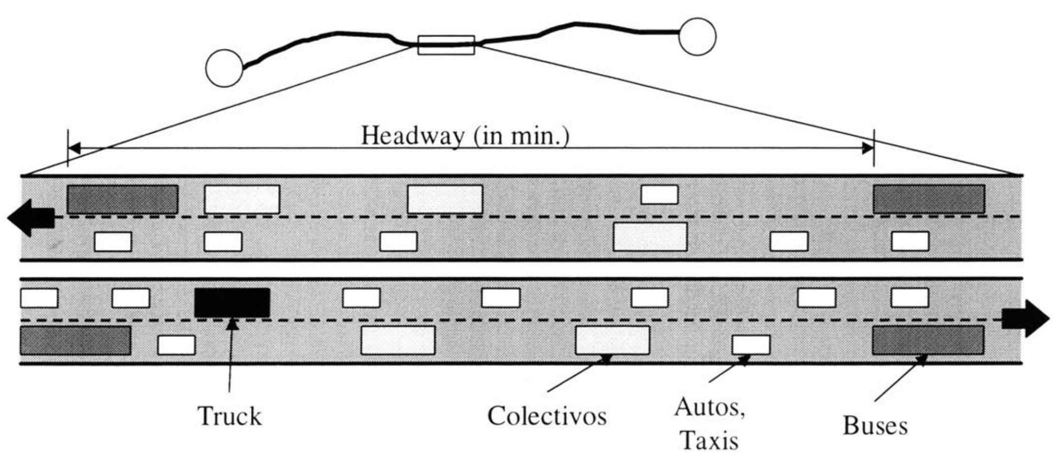


Figure 3-4: Graphic Representation of a Corridor and Modes

Level of Service (LOS):

The level of service is primarily a function of volume. As volume approaches capacity, LOS deteriorates dramatically.[58] In Mexico City, the abundance of colectivos on the inadequate road network is believed to cause congestion and reduce LOS for all users of the road. However, colectivos have proved to be a popular mode despite their premium fare. The high frequency of colectivo service is a major reason for the precipitous decline of bus patronage on many corridors where they compete directly. The buses typically travel at lower speeds than colectivos, come less often, and stop only at predetermined places. The combination of these factors translates into a lower quality of service for buses and helps explain the dominance of colectivos in Mexico City.

Operating policy is also a key determinant of level of service.[59] For instance, colectivos often wait at terminal stations to fill their vehicles with passengers. This is done to ensure a profitable load of passengers for the trip. The result is that the vehicle loads for colectivos tend to be high and more stable in a highly variable demand condition (Figure 3-5). It also results in longer wait times for colectivo passengers and a lower level of service. A scheduled bus service, on the other hand, tends to operate on predetermined, equal headways. This has a significant impact on bus occupancy under variable demand. Figure 3-5 illustrates the difference between colectivo and bus operating practices as time progresses over the course of a day.

[58] Sussman (2000)
[59] Ibid.

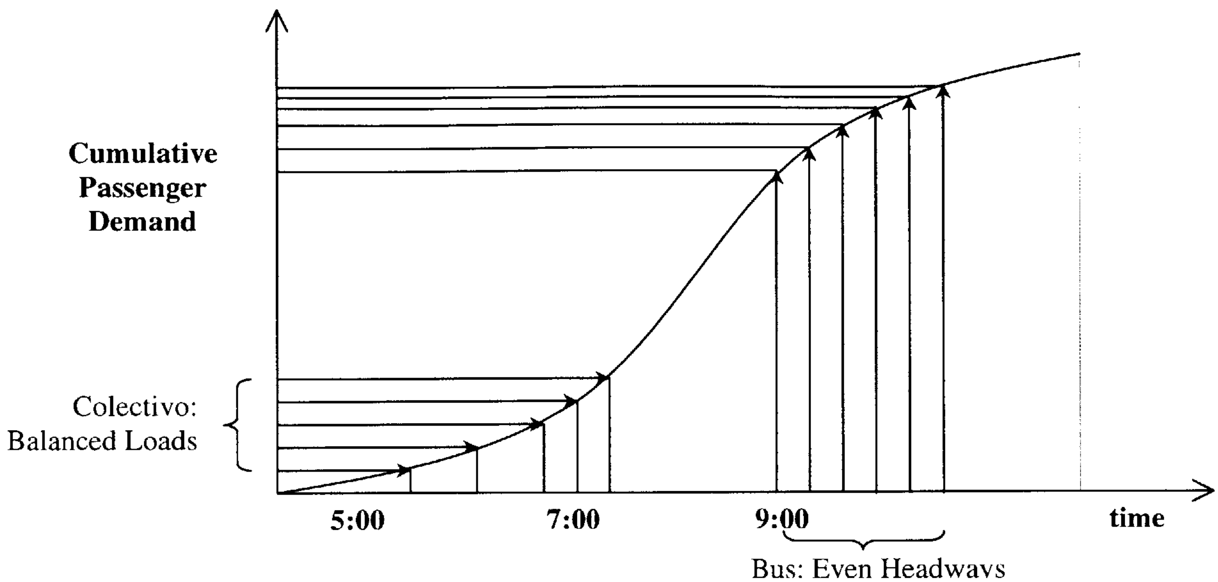


Figure 3-5: Bus and Colectivo Operating Practices

Mode Shares:

The reference case of the corridor model assumes that parallel bus and colectivo routes share the road with private automobiles, trucks, and taxis. The number of passenger trips is first split between public transport and non-public transport modes based on the corridor mode share data in COMETRAVI (1999). The mode shares for trucks, autos, and taxis (all non-public transport modes) are assumed not to be affected by the competition between colectivos and buses and are taken directly from the data. Trucks, autos, and taxis are included so that congestion on the road can be modeled. The mode split between bus and colectivos, however, is variable and based on the relative difference between the total trip costs of each mode. Decisions are therefore made at an individual public transportation user level. Total trip, wait time, and travel time costs are calculated as follows:

Total User Travel Cost = (Wait Time Cost) + (Travel Time Cost) + (Average Fare) (1)

Wait Time Cost = 0.5(Headway)*(Value of Time)* (2)

*Travel Time Cost = [(Avg. Trip Distance)/(Avg. Corridor Speed)]*Value of Time* (3)

A reasonable value of time of $15 pesos per hour (about US$1.50) for auto and taxi riders, and $10 pesos per hour (about US$1.00) for bus and colectivo passengers is used in the wait time and travel time calculations. This is based on a World Bank (1992) recommendation of doubling the minimum daily salary ($40 pesos in Mexico City) yielding an average of $10 pesos per hour for public transportation user. Since private vehicle users typically have higher incomes, their value of time is assumed 50% greater.

Empirical data from Mexico City in 1996 was gathered from two separate tables in the first volume of COMETRAVI[60]. The first table contains the mode split between bus and colectivo on several corridors. The second contains the vehicle counts at peak hour on several major corridors. The combination of these tables relates the frequency of public transport service with the mode split on five major corridors. Although this data is very limited, it serves the purpose of developing an illustrative mode split model for public transport modes on major corridors in Mexico City.

The five corridor data points were first plotted to understand the tradeoff between the relative frequencies of the bus and colectivo with respect to their mode shares. Figure 3-6 presents this data and a best-fit logarithmic curve. Note that the colectivo mode share would be 32% if the bus and colectivo ran at the same frequency and travel time. This is because the average colectivo fare is about 1.77 times higher than the bus in 1996. In reality, the wait time is lower for the users of the typically more frequent colectivos and the fare favors the typically cheaper buses.

Figure 3-7 is the final mode choice model used to determine the mode split of passenger-trips between the colectivo and the bus. The symmetric s-shape is based on assumption that all distinguishing characteristic of the two modes have been captured with the total user cost measure. This is a key simplification as other factors such as comfort, access time, and other features are assumed equal. The feasible range of the model depends on the relative difference of total user costs, from -$2.00 to $2.00 pesos. This model predicts that all public transportation passenger trips be attributed to one of the two modes beyond this range. The model also has been constrained so that when total user costs are equal, and therefore the relative difference is zero, the mode split between bus and colectivo is also equal.

Figure 3-6: Colectivo Mode Share Relative to Bus-Colectivo Frequency

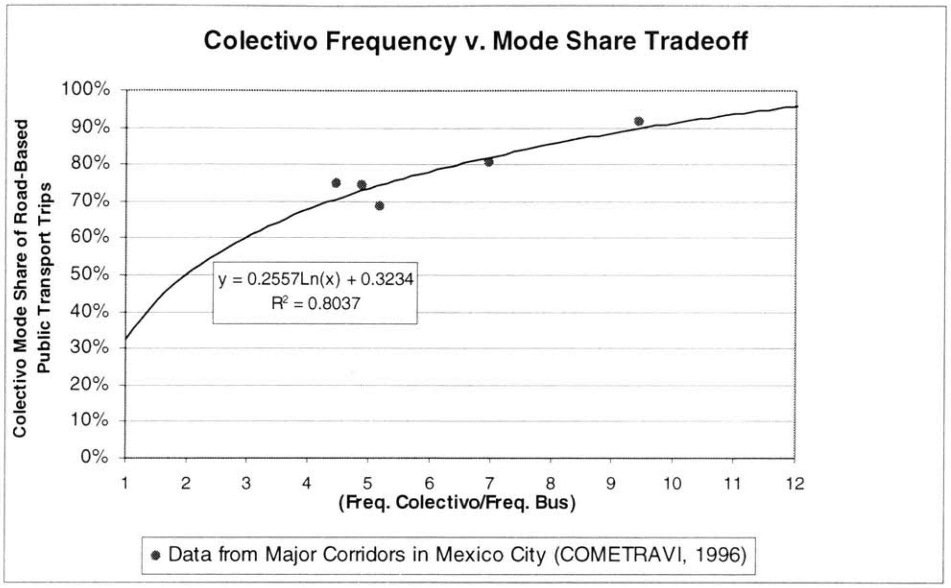
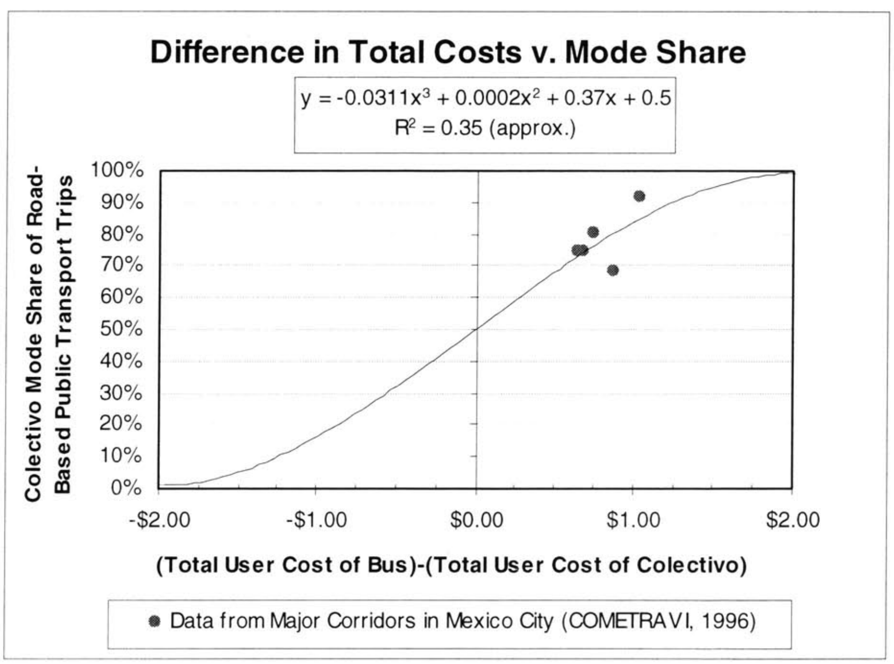


Figure 3-7: Public Transportation Mode Choice Model



[60] COMETRAVI (1999) v.1, pp. 31-33

The lack of corridor data from Mexico City, save five points, made numerous simplifying assumption (and the associated limitations) necessary to construct this model. First, the lack of corridor data from Mexico City where the bus captures a greater mode share than the colectivo explains the lack of data points in the first half of the curve in Figure 3-7. The curve reflects reasonable assumptions, but individual results should not be used directly. Second, the model requires demand to be known *a priori*. Third, no mode switching between public transportation (bus and colectivo) and non-public transportation (auto and taxi) is considered. Essentially, public transport users are "captive" and do not switch to auto or taxi and vice versa. There may also be errors due to the distinguishing characteristics between the modes not considered such as comfort (with respect to occupancy), access time to stop or station, and pick-up or drop-off points. Despite these limitation, this mode choice model is a useful approximation for the purposes of this analysis, which is to compare various strategies.

Behavior of Operators:

Colectivo vehicles are assumed to operate an average of 12 hours per day and 320 days per year.[61] Since colectivo operators are profit maximizing, they try to maintain vehicle occupancies near capacity during the peak hours and operate for as long as it is profitable. With no fixed schedules, colectivo vehicles may be held at their origin until they have a certain number of passengers. The model reflects the reality that the colectivo operators react to changes in the demand or the bus frequency by adjusting their own frequency. This is evident when one considers that colectivo operators can vary the number of vehicles of the fleet in operation on a daily, even hourly basis. The bus, on the other hand, is assumed to operate a scheduled service that runs at a pre-determined frequency that is not easily changed.

Fares and Trip Distances:

Since the corridor model uses corridor data from COMETRAVI (1999) collected in 1996, default fares are a flat $1.00 peso for buses and an average fare for colectivos of $1.77

pesos. The colectivo fare varies by distance as shown in Table 3-1. The average trip distance for both bus and colectivo riders is assumed 8.4 km.

Table 3-1: Colectivo Distance-Based Fare Structure

Trip Length (Km)	1996 Colectivo Fares ($ Pesos)	Percent of Total Passengers	Assumed Avg. Trip Length (Km)
0 - 5	1.50	63.3%	5
5 - 12	2.00	20.4%	10
12 - 17	2.50	6.1%	17
> 17	2.50	10.2%	17
Average or Total	**$1.77**	**100.0%**	**8.4**

Sources: INE Colectivo Study in the DF (1994) as cited in COMETRAVI (1999)

Travel Time:

To explain the faster travel time observed for the colectivos relative to the bus, the average dwell time of vehicles at stops was considered. The dwell time is believed to related to the passenger load, operating practices, and acceleration/deceleration performance. Colectivos typically stop anywhere along the route at passenger request. However, since the passenger load of a colectivo microbus is typically lower than the bus (due to a lower capacity) and can accelerate and decelerate slightly faster, it is believed that it dwells less on average than the bus despite stopping more often. As a result, the total dwell time is assumed proportional to the passenger capacity of a vehicle. To reflect this, a dwell time constant of 1.5 seconds per passenger capacity per kilometer was derived from the calibration of the model with empirical data and applied to both bus and colectivo.

Average Speed

The travel time is directly calculated from the average speed of each mode on the corridor. In turn, the average speed is a function of the dwell time, recovery time (assumed to be 5 minutes), and the volume-to-capacity ratio, which is the measure of road congestion. Figure 3-8 shows a typical V/C and speed relationship for a class II

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[61] Based on COMETRAVI (1999) v.7 and notes from the interview of Julio Figueroa (April 2000)

road derived from COMETRAVI (1999). The V/C ratio determines the average speed depending on the type of corridor.

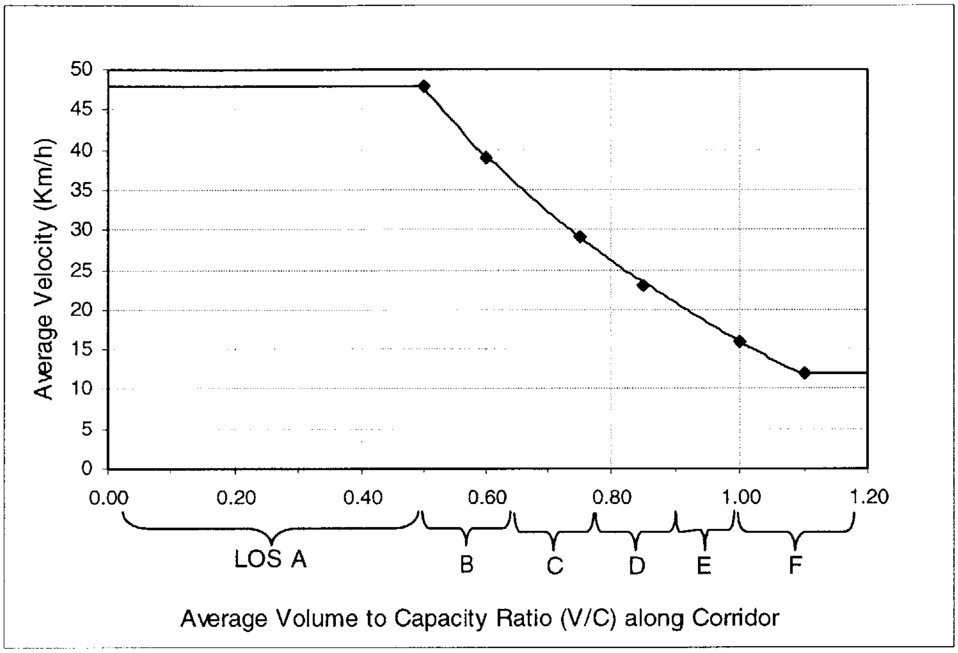

Figure 3-8: V/C-Speed Relationship for a Class II Roadway

The V/C ratio can also be translated into a roadway level of service (LOS) measure. As shown in Figure 3-8, this varies from LOS A to F and indicates the average level of congestion along the corridor. In the model, four categories of corridor congestion were considered for every measure tested: (1) an uncongested condition (free-flow or LOS A), (2) fair condition (LOS B or C), (3) congested condition (LOS D or E), and (4) highly congested condition (LOS E or F). The highly congested condition is illustrated in Figure 3-9.

Figure 3-9: Highly Congested Arterial Road in Mexico City
Source: http://www.reforma.com

Travel Delay:

Related to the notion of congestion is a measure of travel delay. In the model, delay time for any particular passenger is calculated using the following equation:

Delay Time = Actual Travel Time - Free Flow Travel Time (4)

The delay time for a passenger on a particular corridor, therefore, is the difference between the travel time when the corridor is at free-flow conditions (LOS A) and the actual travel time.

Operational Costs and Revenue:

Operating costs are assumed a function of both fixed costs and variable costs. In turn, annual fixed costs is a function of a number of factors that dependent on the vehicle price (as shown in Figure 3-10) and the driver salary ($45,000 pesos per year for bus drivers and $40,000 pesos per year for colectivos drivers). The factors that depend on the price include depreciation (20% of vehicle price per year), interest (10% of vehicle price per year), and insurance (3% of vehicle price per year). In addition, the cost for administration and overhead is also considered at a rate of 20% and 7% of annual fixed costs for the bus and colectivo, respectively. The variable costs include fuel and maintenance. The annual maintenance costs is composed of 20% of the annual fuel cost, 10% of the price of the vehicle per year, and tire costs at a rate of 2% of total variable costs per year.[62]

Revenue for buses and colectivos is a function of the number of passengers and the fare. The number of passenger depends on the mode share captured by each mode.

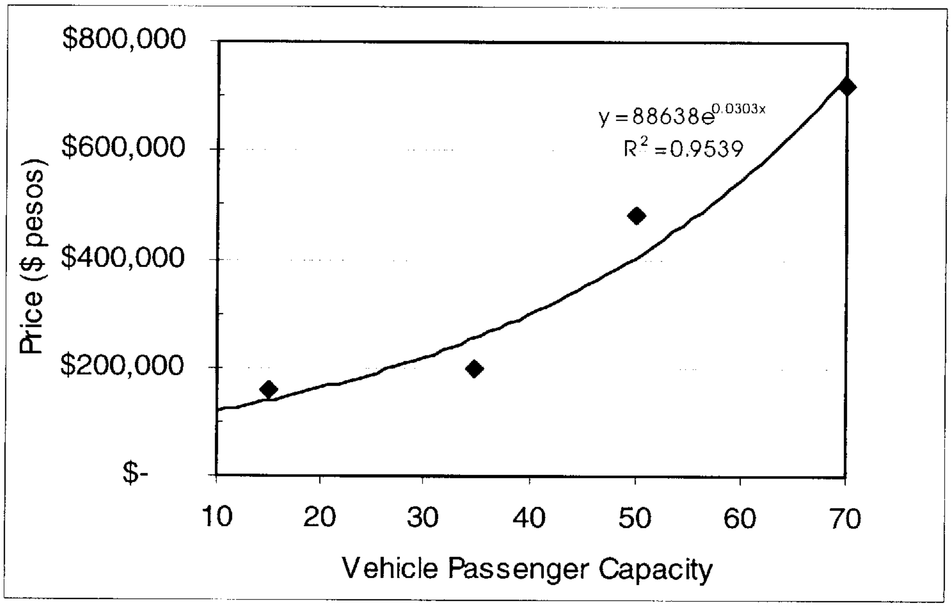

Figure 3-10: Assumed Capital Cost of New Vehicle by Capacity[63]

3.3.3 Emissions Component

The emissions component of the corridor model uses the vehicle-kilometers traveled (VKT) and the average speed from every mode as inputs to calculate the mass of each pollutant emitted. The figures below show the average speed curves for HC, CO, and NOx emissions from the MOBILE 5 model results in COMETRAVI (1999) developed using Mexico City vehicle fleet characteristics. Three categories of vehicles were

[62] Based on methodology used in GTZ report for SETRAVI (2000)

considered, light duty gasoline vehicles (most autos and taxis), light duty gasoline trucks (most colectivos), and heavy-duty diesel truck (most trucks and buses). Table 3-2 presents emission factors for two pollutants that are assumed invariant with vehicle speed.

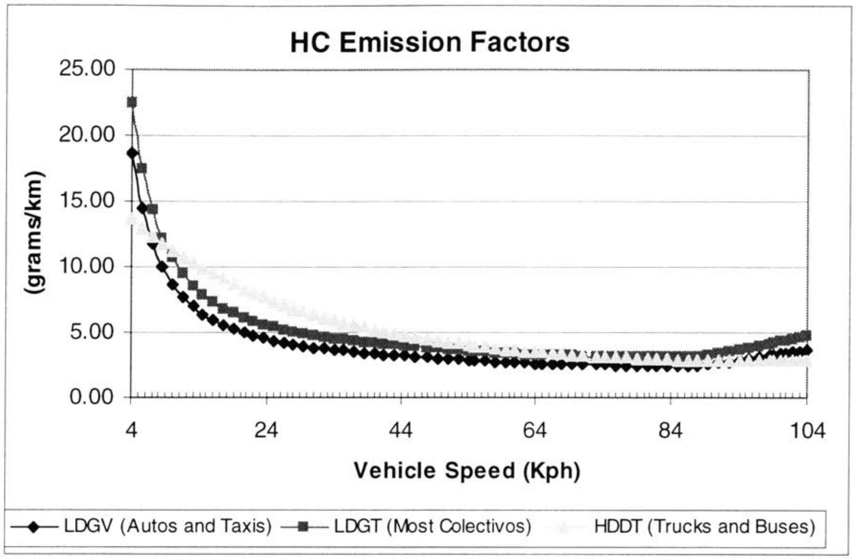

Figure 3-11: HC (VOC) Emissions vs. Speed Curve

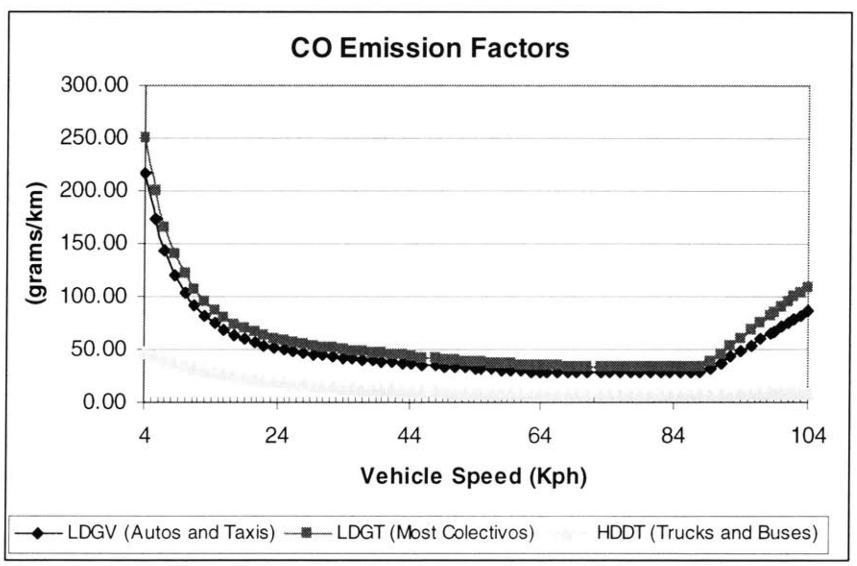

Figure 3-12: CO Emissions vs. Speed Curve

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[63] Based on figures from a DF government news release and *la Reforma* newspaper classifieds

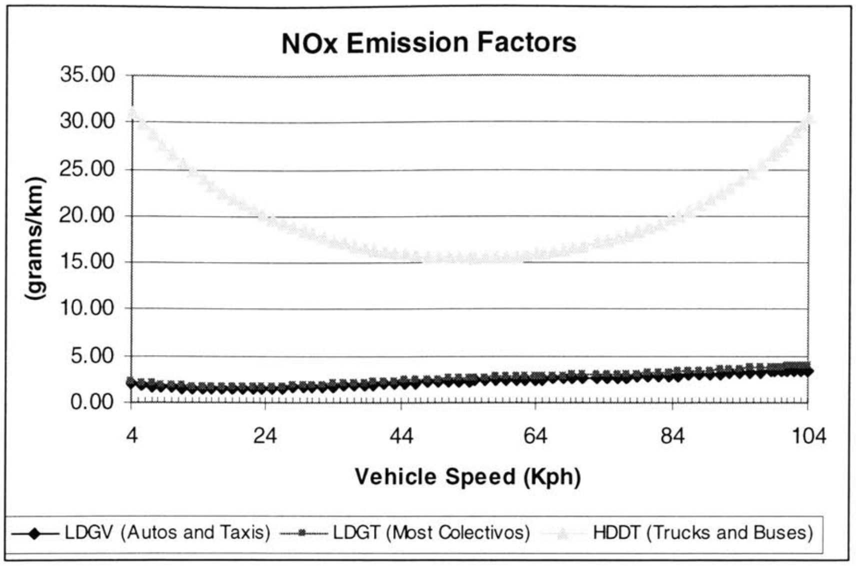

Figure 3-13: NOx Emissions vs. Speed Curve

Table 3-2: Other Emission Factors Invariant with Vehicle Speed

	Auto	Bus	Colectivo	Taxi	Trucks
PM-10 (g/km)	0.029	1.5	0.029	0.029	1.5
SO_2 (g/km)	0.09065	0.3157	0.11497	0.09065	0.3157

Source: Factors based on CAM, "Inventario de Emisiones a la Atmosfera de la ZMVM 1998":

3.4 Model Development

3.4.1 Flow Diagram

Figure 3-15 is a flow chart of the corridor model. The shaded boxes are empirical data gathered from COMETRAVI (1999) or other Mexico City sources. The dark boxes are model results, namely emissions, operational costs, revenues, and mobility costs. In this study, total user trip costs are used as a proxy for the (dis)utility of mobility. The circular arrow indicates that the colectivo frequency and mode split are calculated iteratively until the model converges on a solution.

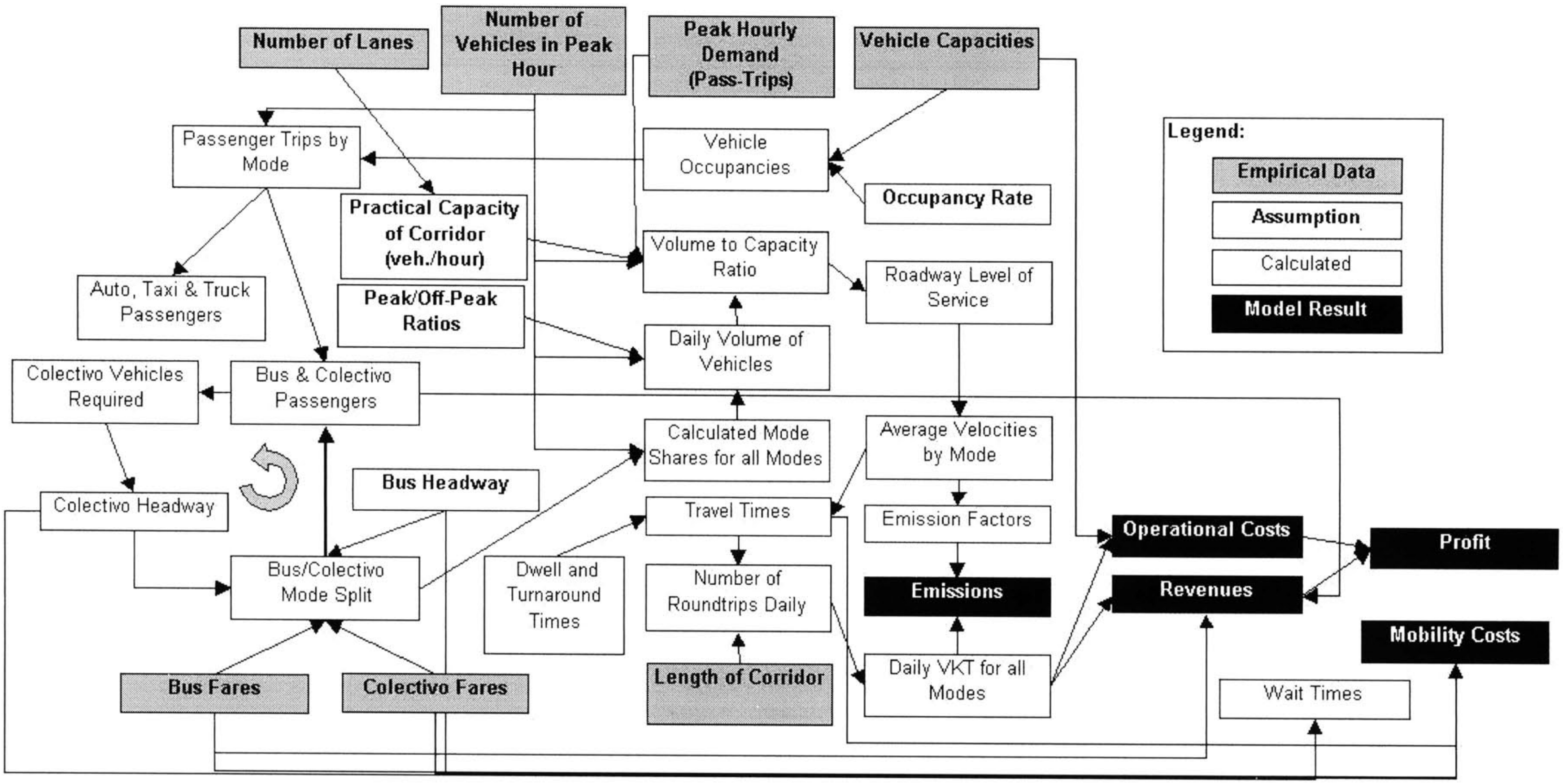

Figure 3-14: Corridor Model Flow Diagram

3.4.2 Calculations

A representative corridor was selected from the five available data points to demonstrate and test the model.[64] The selected corridor was Avenida Tláhuac, an 8-lane class II arterial (4-lanes in each direction) in Mexico City with an approximate length of 15 km. The fare used is $1.00 peso for the bus and an average fare of $1.77 pesos for the colectivo in 1996. Since the data used from COMETRAVI (1999) was gathered in 1996, these figures reflect the actual fares at that time. Table 3-3 is a summary of the initial calculations performed by the model. Detailed print-outs of the model calculations and results are found in Appendix A.

Table 3-3: Summary of Calculations

	Auto	Bus	Colectivo	Taxi	Truck	Total
Observed Vehicles in Peak Hour	817	34	237	182	81	1351
Observed Modal Split	60%	3%	18%	13%	6%	**100%**
Vehicle Capacity (Pass.)	5	70	35	3		
Avg. Vehicle Occup. (Pass.)	1.5	24	14	0.75		
Passengers in Peak Hour	1226	803	3335	137		**5500**
Obs. Bus/Colectivo Mode Split		19.4%	80.6%			**100%**
Equivalencies	1	2	1.425	1	2	
Equiv. Vehicles	817	68	338	182	162	**1567**
Roadway Capacity	3000		**V/C =**	**0.522**	**LOS =**	**B**
Average Speed (Km/hr.)	45.6	19.6	29.1	45.6	45.6	
Cycle Time (min.)		92.7	65.2			
Required Fleet		53	258			

First, the number of vehicles observed is used to compute a modal split by vehicle type on the corridor. The number of passengers riding automobiles and taxis can be calculated directly using the assumed average vehicle occupancies of 1.5 and 0.75, respectively.[65] This results in an estimated 1,226 auto and 137 taxi passenger trips in the peak hour and peak direction.

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[64] Unless otherwise stated, all data in this section are from COMETRAVI (1999) v.7, pp.31-33, which reports intersection and vehicle counts for Avenida Tláhuac at Calz. Tasqueña.

[65] Automobile occupancy is based on COMETRAVI (1999) while taxi occupancy conservatively assumes that the VKT to PKT (passenger-kilometers traveled) ratio is 75% for taxis on the road.

The public transportation trips in the peak hour are estimated from the total daily public transport passenger trips observed on the corridor using several assumptions. First, a typical day is composed of 6 peak hours and 12 off-peak hours. An off-peak hour receives 70% of the demand compared to a peak hour. This equates to 42% of the daily passenger demand occurring in the peak period. Second, the peak direction of the corridor is assumed to carry 55% of the passenger demand. Therefore, a total daily demand of 59,073 public passenger trips for the corridor in the peak direction in COMETRAVI (1999) translates into about 4,138 bus and colectivo trips in a peak hour. Adding this value to the auto and taxi trips yields about 5,500 passenger trips for the corridor per peak hour in the peak direction. The 4,138 public transport trips now must be split between bus and colectivo. COMETRAVI (1999) provides the observed bus/colectivo mode split data for the corridor. Table 3-3 reflects the observed mode split of 19.4% and 803 passengers for bus and 80.6% and 3,335 passengers for colectivo. Using these figures, it is possible to estimate the average vehicle occupancy per bus or colectivo.

Using the assumed vehicle equivalencies for the modes tested, a total number of equivalent vehicles was calculated at 1,567. This number of equivalent vehicles is divided by the roadway capacity of 3000 (4 lanes with 750 equivalent vehicles per hour in each) to yield the V/C ratio of 0.522. As described previously, this ratio translates into a level of service of B and an average corridor speed of 45.6 km/h. However, since transit vehicles must stop to pick up and drop off passengers, their speed must also reflect a dwell time and a recovery or turnaround time. The dwell time is assumed to be a function of the capacity of the vehicle while the recovery time is a constant 10 minutes per corridor cycle. A cycle time can now be calculated based on the travel time in the peak direction and similarly calculated for the off-peak direction. The required fleet of buses and colectivos is then the observed number of vehicles per hour (frequency) divided by the cycle time yielding 53 and 258, respectively. The cycle time is also calculated for the off-peak periods using the reduced demand assumption. With cycle time for both peak and off-peak periods, it is possible to calculate the number of roundtrips a vehicle can make in one working day. Multiplying the roundtrips with the required fleet of buses and colectivos per period yields the VKT per day. This is then multiplied by the emissions factors for the five key pollutants, three of which are speed dependent, to yield the emissions per mode per day. The daily VKT figures are also key inputs to the operating cost model for both bus and colectivo. With a revenue estimate using the number of passenger per mode, a profit calculation is simply the difference between the operating costs and the revenue.

One of the purposes of the corridor model is to simulate the competition between road-based public transport modes and test several measures that may affect the mode split. Therefore, the mode choice model described previously can be used to generate a bus/colectivo split based on the relative total travel costs of the users by mode (see Equation 1). As described previously, the total travel cost is a proxy for the (dis)utility of mobility and is a function of the travel time, wait time, and fare for transit modes. This is the start of an iterative calculation where the total travel cost per passenger (TTC) is calculated from the frequency, fare, and other key parameters of the bus and colectivo service. The relative difference in TTC drives the passenger mode spit between buses and colectivos and the number of colectivo vehicles operating because they are assumed to respond to variable demand in a relatively short time. Since the number of colectivo vehicles is variable, the frequency of service and therefore the TTC may also vary. Similarly, the level of road congestion and therefore the average speed may also vary according to the number of colectivos operating.

The mode choice model predicts 24.0% for the bus and 76.0% for the colectivo under these assumptions. The difference between the observed mode split and this calculated mode split is carried through the rest of the calculations for mobility costs and emissions. The difference in these two sets of solutions suggests a measure of the model error with respect to the actual corridor conditions. Based on this methodology, the suggested model error for this particular corridor is ±12.2% for emissions and ±7.8% for mobility. Therefore, we can assume that the difference in strategies from the reference within those bounds are not likely to be meaningful.

3.5 Options for Emissions Reductions

Numerous measures have been investigated and implemented to reduce emissions in urban areas. A list of policies and strategies to reduce transportation emissions is presented in Table 3-4.

Table 3-4: Policies and Strategies for Transportation Emissions Reduction

Category	Measure	Examples
Land-Use and Urban Form	• Mixed Use Development • Zoning	• Urban growth boundary
New or Alternative Technologies	• More Fuel Efficient Vehicles • More Fuel Efficient Modes • Alternative Fuels • Emissions Control	• U.S. Corporate Average Fuel • CNG buses • Catalytic converters
Transportation System Design and Operation		
System Integration	• Modal • Network • Institutional	• Fare integration
Supply Expansions	• New streets, freeways, exclusive busways, rail lines, and pedestrian and bike	• Installing a new busway
Capacity Enhancements	• HOV priority on existing • Traffic signal synchronization • Signal priority for high-	• Reserving a busway by taking away a lane
Demand Management	• Pricing mechanisms: parking, tolls, fuel taxes • Vehicle restrictions on • Flexible work hours • Telecommuting	• Congestion tolls • Transit fares • Hoy No Circula

Source: Author and Zegras et al. (1995)

The effectiveness of these options is usually measured in the cost per ton of pollutants reduced. In order to compare measures that have differing affect on the pollutants of interest, a toxicity weight factor can be applied to each pollutant. These factors are based on scientific evidence of the impact of each pollutant and the specific conditions of the region where they are applied. Nonetheless, these factors are subject to significant scientific uncertainty and debate. The weight factors presented in Table 3-5 were used to normalize the emissions into equivalent units and are estimated using from several sources in the literature including Litman (1999) and COMETRAVI (1999).

Table 3-5: Approximate Toxicity Weight Factors of Key Pollutant

NO_x	CO	SO_x	PM10	VOC
5	1	3	6.5	2.5

Sources: Author's estimate based on Wang (1995) as cited in Litman (1999) and COMETRAVI (1999) v.7, pp.130.

Most measures can be categorized using a simple equation for emissions where,

$$\textit{Pollution} = \underbrace{[\textit{Vehicles}]}_{(1)\text{ Ownership}} * \underbrace{[\textit{VKT/Vehicle}]}_{(2)\text{ Use}} * \underbrace{[\textit{Emission/VKT}]}_{(3)\text{ Technology}} \qquad (5)$$

Regulation on the number of vehicles such as a tax on new vehicle purchased affects term (1) of Equation 5. Other options such as demand management, mandated carpooling, and high fuel taxes have an impact on term (2) of the equation. These measures result in a reduction of the vehicle kilometers traveled per vehicle or person. These two types of measures are very often politically infeasible except under exceptional circumstances. In Singapore, for example, an authoritarian government has been able to implement road pricing and demand controls that have had a measurable effect on the number of vehicles and their use (i.e., VKT/vehicle).

Lastly, other measures such as emissions standards, fuel economy standards, alternative fuels, and speed limits have an impact on term (3). This results in a reduction in the grams of pollution emitted per kilometer traveled. On the other hand, vehicle aging causes a degradation of emissions technology and therefore also affects term (3). This type of measure tends to place the burden on vehicle manufactures and is politically more viable. The United States has had extensive experience with technology or performance-based standards. The U.S. Corporate Average Fuel Efficiency (CAFE) regulation is a prime example.

3.6 Modeling Results

3.6.1 Selected Corridor

Using 1996 data from Avenida Tláhuac, as described previously, a number of measures were tested for their effects on mobility and emissions. The underlying hypothesis is that the level of congestion highly influences the impact of the strategies tested. To account for this, all measures were tested under four levels of corridor congestion. The level of congestion was changed by varying the total travel demand on the corridor (i.e. number of passenger trips) as follows:

- Uncongested (LOS A-B): 5,000 passenger trips in the peak hour
- Fair (LOS B-C): 7,500 passenger trips in the peak hour
- Congested (LOS C-D): 10,000 passenger trips in the peak hour
- Heavily Congested (LOS E-F): 12,500 passenger trips in the peak hour

Other corridor characteristics, such as length, mode split, geometry, traffic signaling, are also significant. For the purposes of this analysis, however, only the level of congestion was varied in the results presented.

3.6.2 Options and Strategies Tested

The purpose of the model is to quantify the tradeoffs between mobility and emissions by performing a sensitivity analysis of key operational, tactical, and strategic options as presented in Table 3-6. Operational strategies are relatively easy to change in the short-run. Tactical options, such as installing or reserving an exclusive right-of-way for public transportation, are more difficult and could involve capital infrastructure investment. For the purposes of this analysis, *reserving* a lane means taking an existing lane away from mixed traffic, whereas *installing* a lane means constructing a new lane segregated from the existing roadway. Other strategic options such as the total travel demand on a corridor are difficult to change significantly in the short-term, but are considered in making long-term forecasts.

Table 3-6: Options Tested by the Corridor Model

Level	Time Horizon	Variables/Measures Tested
Operational	Short	Fares (bus and colectivo) Bus Frequency Colectivo Vehicle Capacity
Tactical	Medium	Installing a Dedicated Lane/Right-of-Way Reserving a Dedicated Lane/Right-of-Way
Strategic	Long	Corridor Demand Practical Capacity of Road

The methodology for this analysis included the reduction of systematic errors by calculating the difference between the model output for a corridor with an option in effect and the reference case without the option. The reference case used in these results is the model prediction under the original corridor conditions, as they were observed in 1996. This is because most data used in developing the demand and supply models were gathered from major corridors in 1996. The reference case, unless otherwise stated, includes gasoline microbuses of a maximum capacity of 35 with an average fare of $1.77 pesos, buses of a capacity of 70 with a fare of $1.00 peso, and a bus frequency of 34 buses per hour during the peak period.

3.6.3 Evaluation Framework

All model results are plotted using the framework illustrated in Figure 3-15. Along the x-axis is the change in total daily trip costs (i.e., mobility costs) relative to the reference case measured by the change in total travel cost of all travelers along the selected corridor with the option tested. The total travel cost, as shown in Equation 1, includes the wait time, travel time, and fare costs for public transport users and the travel time costs for automobile and taxi riders. Along the y-axis is the change in the total adjusted emissions from all vehicles on the selected corridor relative to the reference case. The total adjusted emissions is the sum of the individual pollutant emissions which are normalized using the weight factors described earlier in Table 3-5.

The two axes form quadrants that are useful in categorizing the impact of a measure. In the upper right is Quadrant I which represents a highly desirable convergence of both mobility and emissions improvements (win-win). Quadrant II represents a region where emissions along the corridor are reduced, but at the expense of mobility (lose-win). Quadrant III is an undesirable region where both mobility and emissions worsen (lose-lose). Finally, Quadrant IV represents a region where mobility is enhanced while emissions increase along the corridor (win-lose).

In addition, the size of the points or symbols indicates the passenger trip demand and therefore the relative level of congestion along the corridor. A single line connecting four points indicates how the impact of the measure would vary under four levels of congestion as described previously. The following section describes and illustrates the model results using this framework.

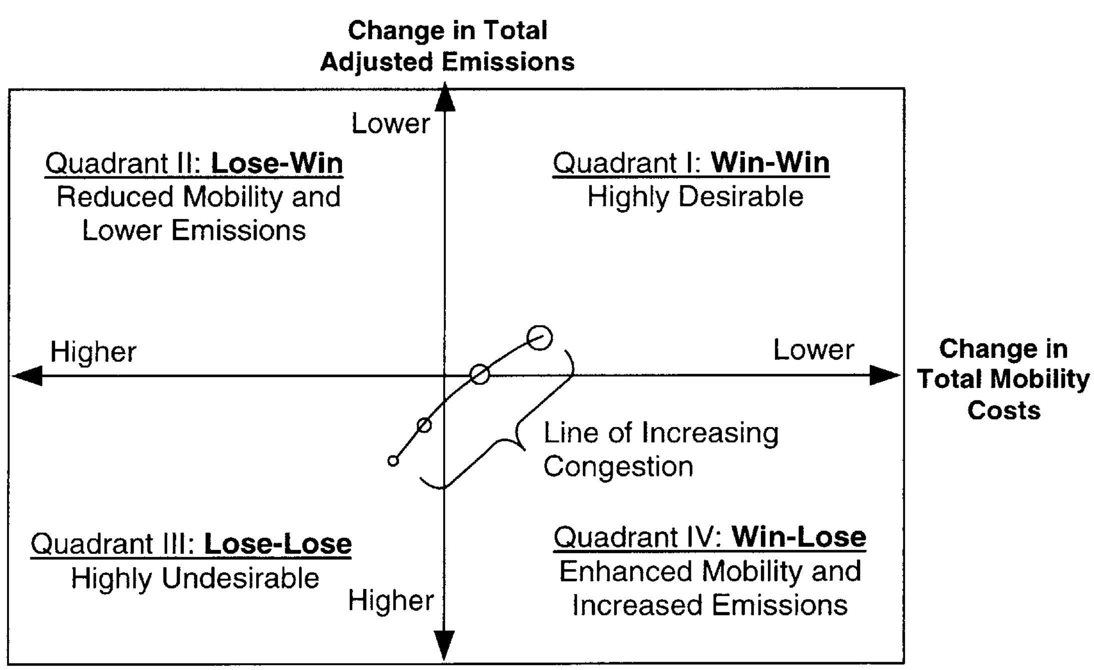


Figure 3-15: Mobility and Emissions Evaluation Framework

3.6.4 Results of All Strategies Tested Separately

Figure 3-16 shows that no single strategy, under any of the congestion levels considered, improved both mobility and emissions (Quadrant I) more than 5% each. Three measures, replacing colectivo microbuses with new or used buses (A & B) and decreasing the bus fare (D), produced the most significant win-win results but were not beyond the model error as discussed in Section 3.4.2.

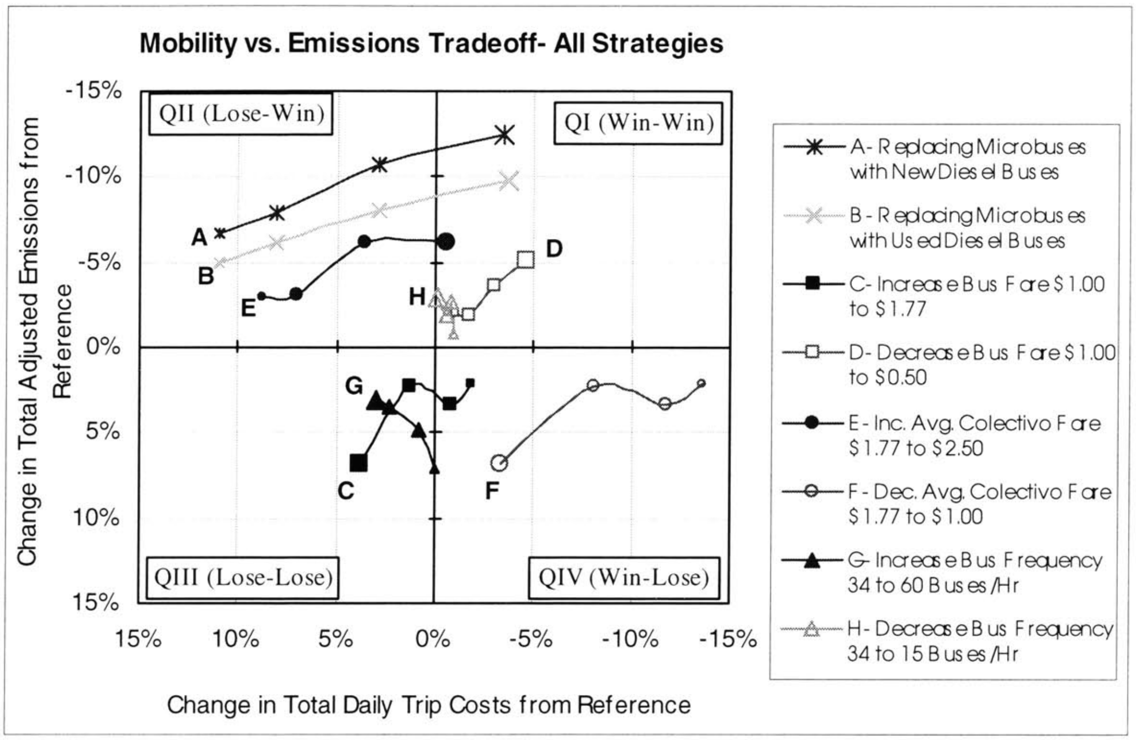


Figure 3-16: Model Results for All Strategies Tested Separately

The most surprising finding is that a decrease in bus frequency (H) seems to improve both mobility and emissions very slightly. Similarly, an increase of bus frequency (G) worsens emissions and mobility slightly. This may suggest that, in this particular corridor and under the conditions tested, the bus is not the most efficient provider of public transportation service from both a mobility and emissions standpoint. Perhaps some of the bus passenger trips would be better served by increasing the number and occupancy of colectivo vehicles. This is mostly a consequence of the faster average travel time of a colectivo trip in comparison with the bus. Furthermore, the slight emissions reduction resulting from strategy (H) is reflects the observation that the slight increase in road congestion caused by the additional colectivo vehicles is more that offset by the decrease in bus VKTs along the corridor. It is important to note, however, that both mobility and emissions results are heavily dependent on the corridor parameters and numerous model assumption about demand and the response of colectivos.

Increasing the bus or colectivo fare (C & E), under most conditions of congestion, reduces mobility by increasing total travel costs. However, under very congested conditions, increasing the average colectivo fare would slightly improve mobility by reducing colectivo ridership and therefore the number of colectivo vehicles circulating. Moreover, in uncongested conditions, increasing the bus fare would actually improve mobility slightly by inducing a shift of road-based public transportation trips to the faster colectivo.

Finally, the strategy of decreasing the average colectivo fare (F) is representative of a tradeoff between enhancing mobility and increasing emissions. The extra demand generated from the lower fare results in additional colectivo vehicles in circulation. Similarly, a strategy of replacing colectivo microbuses with smaller 15-seat passenger vans (not shown in Figure 3-16), as expected, would result in a significant mobility improvement due to reduced wait times while emissions would increase by more than 20% under congested conditions. Table 3-7 summarizes the effect of all strategies tested on the operations, finances, and emissions of vehicles along the corridor.

Table 3-7: Summary of Model Results

Strategy/Option Variable Range Units	Hour Demand (Pass. Trips)	OPERATIONAL IMPLICATIONS: Road LOS: Orig. Peak Per.	Peak Per. After	Colectivo: Orig. Mode Share	Change in Mode Share After	ECONOMIC/FINANCIAL IMPLICATIONS: Change in Profit: Bus Fleet Profit	Colectivo Fleet Profit	Colectivo Profit per Vehicle	Change in Total Trip Costs: Bus Pass.	Colectivo Pass.	Total Pass. Costs for All Modes	Net Effect on Mobility	EMISSIONS IMPLICATIONS: Change in Emissions from All Modes: HC	CO	NOx	PM10	SO2	Total Emissions	Total Adjusted Emissions	Overall Effect on Emissions
A- Replacing Microbuses	5000	A	A	75.8%	-44.5%	$ 45,318	$ (20,389)	$ (328)	0.0%	28.8%	11.0%	**Loss**	-8.1%	-10.3%	0.2%	4.5%	-5.1%	-9.1%	-6.6%	**Win**
with New Diesel Buses	7500	B	B	76.4%	-41.3%	$ 61,889	$ (29,461)	$ (320)	-1.6%	23.1%	8.0%	**Loss**	-10.2%	-12.1%	1.9%	7.9%	-5.3%	-10.9%	-7.9%	**Win**
From 35 to 70 Passengers	10000	D	D	76.6%	-35.1%	$ 65,754	$ (34,635)	$ (310)	-3.9%	15.3%	2.9%	**Loss**	-14.0%	-15.6%	7.8%	13.4%	-4.9%	-14.2%	-10.7%	**Win**
(EPA98 Emissions)	12500	F	E	76.8%	-36.5%	$ 78,786	$ (29,945)	$ (326)	-6.3%	6.2%	-3.5%	**Win**	-14.7%	-16.3%	6.4%	16.7%	-4.8%	-15.2%	-12.4%	**Win**
B- Replacing Microbuses	5000	A	A	75.8%	-44.5%	$ 45,318	$ (20,389)	$ (328)	0.0%	28.8%	11.0%	**Loss**	-6.6%	-9.9%	4.0%	10.2%	-3.4%	-8.3%	-5.0%	**Win**
with Used Diesel Buses	7500	B	B	76.4%	-41.3%	$ 61,889	$ (29,461)	$ (320)	-1.6%	23.1%	8.0%	**Loss**	-8.4%	-11.6%	7.4%	17.4%	-3.0%	-10.0%	-6.2%	**Win**
From 35 to 70 Passengers	10000	D	D	76.6%	-35.1%	$ 65,754	$ (34,635)	$ (310)	-3.9%	15.3%	2.9%	**Loss**	-11.7%	-15.0%	16.9%	28.8%	-1.6%	-13.1%	-8.0%	**Win**
	12500	F	E	76.8%	-36.5%	$ 78,786	$ (29,945)	$ (326)	-6.3%	6.2%	-3.7%	**Win**	-12.5%	-15.7%	18.0%	35.9%	-1.3%	-14.1%	-9.8%	**Win**
C- Increase Bus Fare	5000	A	A	75.8%	19.4%	$ (15,024)	$ 4,055	$ 0	14.4%	-0.3%	-1.8%	**Win**	2.5%	2.7%	0.9%	0.3%	1.8%	2.5%	2.1%	**Loss**
$1.00 to $1.77	7500	B	C	76.4%	19.1%	$ (22,592)	$ 4,293	$ (4)	14.5%	0.5%	-0.8%	**Win**	4.2%	4.5%	-0.2%	0.4%	1.9%	4.2%	3.3%	**Loss**
Pesos	10000	D	D	76.6%	18.9%	$ (31,022)	$ (1,251)	$ (12)	14.4%	1.9%	1.2%	**Loss**	2.5%	2.5%	1.2%	0.5%	1.9%	2.4%	2.2%	**Loss**
	12500	F	F	76.8%	18.8%	$ (39,819)	$ (14,847)	$ (14)	14.5%	3.9%	3.8%	**Loss**	7.6%	7.8%	2.0%	0.6%	2.0%	7.5%	6.8%	**Loss**
D- Decrease Bus Fare	5000	A	A	75.8%	-18.0%	$ (2,802)	$ (3,791)	$ 0	-9.3%	0.5%	-1.0%	**Win**	-2.3%	-2.6%	-0.8%	-0.3%	-1.6%	-2.4%	-2.0%	**Win**
$1.00 to $0.50	7500	B	B	76.4%	-17.7%	$ (3,594)	$ (4,246)	$ 4	-9.5%	-0.3%	-1.7%	**Win**	-2.3%	-2.4%	-1.0%	-0.4%	-1.8%	-2.3%	-1.9%	**Win**
Pesos	10000	D	D	76.6%	-17.5%	$ (3,623)	$ (172)	$ 11	-9.6%	-1.6%	-3.1%	**Win**	-4.6%	-4.4%	0.0%	-0.5%	-1.8%	-4.2%	-3.6%	**Win**
	12500	F	E	76.8%	-17.4%	$ (3,399)	$ 10,579	$ 13	-9.7%	-3.2%	-4.6%	**Win**	-5.9%	-5.9%	-0.9%	-0.5%	-1.9%	-5.7%	-5.1%	**Win**
E- Inc. Avg. Colectivo Fare	5000	A	A	75.8%	-26.9%	$ 25,865	$ (5,697)	$ 0	0.0%	16.6%	8.8%	**Loss**	-3.5%	-3.8%	-1.2%	-0.4%	-2.5%	-3.6%	-3.0%	**Win**
$1.77 to $2.50	7500	B	B	76.4%	-26.4%	$ 38,438	$ (6,449)	$ 5	-0.8%	14.7%	7.1%	**Loss**	-3.5%	-3.7%	-1.4%	-0.6%	-2.6%	-3.5%	-3.1%	**Win**
Pesos	10000	D	D	76.6%	-26.2%	$ 52,175	$ (720)	$ 17	-2.4%	11.0%	3.6%	**Loss**	-7.9%	-7.8%	0.6%	-0.7%	-2.7%	-7.4%	-6.2%	**Win**
	12500	F	E	76.8%	-26.1%	$ 66,276	$ 14,733	$ 20	-4.5%	6.3%	-0.5%	**Win**	-7.0%	-7.1%	-1.5%	-0.8%	-2.8%	-6.8%	-6.2%	**Win**
F- Dec. Avg. Colectivo Fare	5000	A	A	75.8%	19.4%	$ (18,412)	$ 4,055	$ 0	0.0%	-16.9%	-13.6%	**Win**	2.5%	2.7%	0.9%	0.3%	1.8%	2.5%	2.1%	**Loss**
$1.77 to $1.00	7500	B	C	76.4%	19.1%	$ (27,376)	$ 4,293	$ (4)	0.7%	-15.4%	-11.8%	**Win**	4.2%	4.5%	-0.2%	0.4%	1.9%	4.2%	3.3%	**Loss**
Pesos	10000	D	D	76.6%	18.9%	$ (37,207)	$ (1,251)	$ (12)	2.1%	-12.1%	-8.0%	**Win**	2.5%	2.5%	1.2%	0.5%	1.9%	2.4%	2.2%	**Loss**
	12500	F	F	76.8%	18.8%	$ (47,407)	$ (14,847)	$ (14)	4.2%	-7.5%	-3.3%	**Win**	7.6%	7.8%	2.0%	0.6%	2.0%	7.5%	6.8%	**Loss**
G- Increase Bus Frequency	5000	A	A	75.8%	-2.1%	$(131,015)	$ (600)	$ 0	-1.6%	0.1%	0.0%	--	6.7%	1.5%	16.7%	24.9%	7.5%	3.4%	7.1%	**Loss**
34 to 60	7500	B	C	76.4%	-2.1%	$(133,931)	$ (1,168)	$ (4)	-1.1%	0.7%	0.9%	**Loss**	4.4%	0.9%	14.1%	23.1%	5.4%	2.1%	4.9%	**Loss**
Buses/Hr	10000	D	D	76.6%	-2.1%	$(145,694)	$ (3,207)	$ (12)	-0.1%	1.9%	2.3%	**Loss**	3.0%	0.5%	13.0%	21.5%	4.2%	1.4%	3.4%	**Loss**
	12500	F	F	76.8%	-2.0%	$(164,566)	$ (4,406)	$ (11)	0.6%	2.6%	3.0%	**Loss**	2.7%	1.0%	12.5%	20.1%	3.4%	1.6%	3.1%	**Loss**
H- Decrease Bus Frequency	5000	A	A	75.8%	5.8%	$ 58,401	$ 1,089	$ -	3.1%	-0.1%	-0.2%	**Win**	-2.7%	-0.2%	-7.7%	-11.7%	-3.2%	-1.1%	-3.0%	**Win**
34 to 15	7500	B	B	76.4%	5.8%	$ 57,794	$ 1,564	$ 2	2.6%	-0.3%	-0.6%	**Win**	-1.6%	0.1%	-6.5%	-10.8%	-2.2%	-0.5%	-1.9%	**Win**
Buses/Hr	10000	D	D	76.6%	5.7%	$ 60,530	$ 1,475	$ 3	1.9%	-0.5%	-0.8%	**Win**	-3.2%	-1.8%	-4.8%	-10.1%	-1.6%	-2.1%	-2.7%	**Win**
	12500	F	F	76.8%	5.7%	$ 66,978	$ (422)	$ 3	1.1%	-0.5%	-0.9%	**Win**	-0.5%	0.3%	-5.6%	-9.4%	-1.2%	0.0%	-0.7%	**Win**
I- Replace Colectivos	5000	A	B	75.8%	16.7%	$ (16,361)	$ (37,743)	$ (253)	0.5%	-13.2%	-10.1%	**Win**	16.9%	19.3%	6.7%	2.2%	12.8%	17.9%	14.9%	**Loss**
with Gasoline Vans	7500	B	C	76.4%	16.3%	$ (26,396)	$ (67,013)	$ (244)	4.4%	-8.1%	-3.4%	**Win**	21.4%	23.0%	5.3%	3.0%	13.9%	21.6%	18.2%	**Loss**
From 35 to 15	10000	D	E	76.6%	16.0%	$ (40,616)	$ (127,352)	$ (206)	11.7%	1.5%	8.4%	**Loss**	30.4%	29.6%	6.4%	3.7%	14.6%	28.4%	25.0%	**Loss**
Passengers	12500	F	F	76.8%	15.9%	$ (53,133)	$ (216,340)	$ (141)	13.8%	5.5%	11.8%	**Loss**	35.2%	36.5%	11.6%	4.4%	15.1%	35.3%	32.3%	**Loss**

Key Assumptions:

Roadway Capacity (Equiv. Vehicles per Hour) = 3000

Class II arterial

3.7 Key Findings

Detailed data and modeling is necessary on any individual corridor to understand all the possible consequences of strategies. Nonetheless, Table 3-8 presents the general findings of strategies applied to one representative corridor in Mexico City. Most strategies do not result in a win-win situation for mobility and emissions reflecting the tradeoff that exist between the two objectives.

Table 3-8: Summary of General Findings

Quadrant	Mobility-Emissions Impact	Strategy/Option
I	Win-Win	• Replacing colectivo microbuses with new or used buses in congested conditions • Decreasing the bus fare
II	Lose-Win	• Replacing colectivo microbuses with new or used buses in uncongested conditions • Increasing the average colectivo fare
III	Lose-Lose	• Increasing the bus fare in congested conditions
IV	Win-Lose	• Decreasing the average colectivo fare • Increasing the bus fare in uncongested conditions

All strategies in Quadrant I are difficult to implement in reality. For instance, decreasing the bus fare would mean a higher subsidy from the government. Considering all of the other demands for government resources, this strategy is unlikely to receive adequate political support. Similarly, a plan to replace microbuses with full-size buses would face formidable costs and resistance from colectivo owner-operators. These issues of the political and financial reality and the sustainability of strategies are discussed further in Chapter 4.

The findings generally confirm the notion that the bus is indeed a more efficient supplier of transportation than smaller colectivos in high-demand and congested corridors. In uncongested corridors, where the demand is low, the smaller and faster colectivo vehicles are more effective in providing mobility.

In sum, it is possible to conclude that no single measure studied is likely to produce significant positive impacts (greater than 5%) for both mobility and emissions for this particular corridor. In light of this, it may be useful to package the tested strategies with a dedicated public transportation lane by either taking away a lane from the existing mixed traffic lanes (i.e., reserving) or constructing a new lane (i.e., installing). It is also possible to restrict the use of the reserved or newly installed lane to buses or both buses and colectivos. Table 3-9 is a matrix of the 8 strategies tested in combination with 4 possible right-of-way options, yielding 32 combined strategies. The detailed results of these combinations of strategies on mobility and emissions are found in Appendix B.

The analysis of the combined strategies finds that, *without* considering the induced demand from a supply expansion, installing a new bus or bus/colectivo lane (Option 3 or 4) is generally a win-win option (Quadrant I) in combination with any of the strategies. It increases in effectiveness in highly congested corridors. Reserving a lane for buses only (Option 1) is often a lose-lose option (Quadrant III) that worsens with increased congestion. Reserving a lane for buses and colectivos (Option 2) can have mixed effects (Quadrant II or IV) depending on the level of congestion. On an uncongested road, reserving a lane for both buses and colectivos reduces emissions but may also reduce mobility overall by increasing the delay time of the automobile and taxi passengers. In very congested roadways, the same strategy may improve mobility but increase emissions.

It may be useful in future research to consider the effects of triple combinations of strategies. For example, increasing the bus fare (Strategy C), increasing the bus frequency (Strategy G), and reserving a bus lane (Option 1) may produce a better combined effect on emissions or mobility than any of these strategies alone.

Table 3-9: Combination of Strategies with Dedicated Rights-of-Way

	Right-of-Way Options			
Strategies	(1) Reserving a lane for bus use only	(2) Reserve a lane for both bus and colectivo use only	(3) Install a lane for bus use only	(4) Install a lane for both bus and colectivo use only
(A) Replacing colectivo microbuses with new full-size buses (passenger capacity of 70)	X	X	X	X
(B) Replacing colectivo microbuses with used full-size buses (passenger capacity of 70)	X	X	X	X
(C) Increasing the bus fare	X	X	X	X
(D) Decreasing the bus fare	X	X	X	X
(E) Increasing the colectivo fare	X	X	X	X
(F) Decreasing the colectivo fare	X	X	X	X
(G) Increasing the bus frequency	X	X	X	X
(H) Decreasing the bus frequency	X	X	X	X

3.8 Corridor Model Limitations

The corridor model has numerous simplifications and limitations. It is important to reiterate that its primary purpose is to demonstrate the tradeoffs between mobility and emissions of measures applied to a representative transportation corridor. The use of specific numerical results for other individual cases is not suggested.

The corridor model does not simulate network effects or interaction between corridors, which may be significant. It also does not address changes in mode share between automobiles and taxis with road-based public transport (i.e., buses and colectivos). This is based on the assumption that public transport users are "captive", meaning they have no alternative to the bus or colectivo. As per capita income grows in Mexico City, the validity of this assumption decreases because more people will be able to afford a private vehicle. Lastly, for simplification, the corridor model does not address the effects of congestion on passengers wait time at stops. In reality, the reliability of transit services is highly affected by congestion and stochasticity in general.

3.9 Application to Mexico City

Despite its limitation, the corridor model may be useful in evaluating actual proposed options in Mexico City. For instance, the DF agency responsible for public transport in the DF, SETRAVI, has recently launched a plan to incrementally replace the microbuses with new, full-size buses starting with the oldest vehicles. In the first phase, the oldest 1,800 microbuses are required to stop operating on the first day of 2002. The Mexico City government has set aside $80 million pesos this year in a trust fund intended to provide these vehicle owners financial support towards the purchase of a new bus. This trust fund would supply a loan of about 10% to 15% of the value of a new bus (on the order of $700,000 pesos or US$70,000) to the participating colectivo owners, which is enough to make a downpayment on a 60 month financing plan with the bus manufacturer. In addition, the colectivo owners must scrap their old microbuses to participate in the program. The ultimate objective of the program is to replace the entire fleet of about 28,000 aging gasoline microbuses with 8,000-10,000 new and less-polluting diesel buses.[66] The basic premise is that the current oversupply of colectivos on the road contributes to heavily to congestion and their old and inefficient engines pollute the air disproportionately.

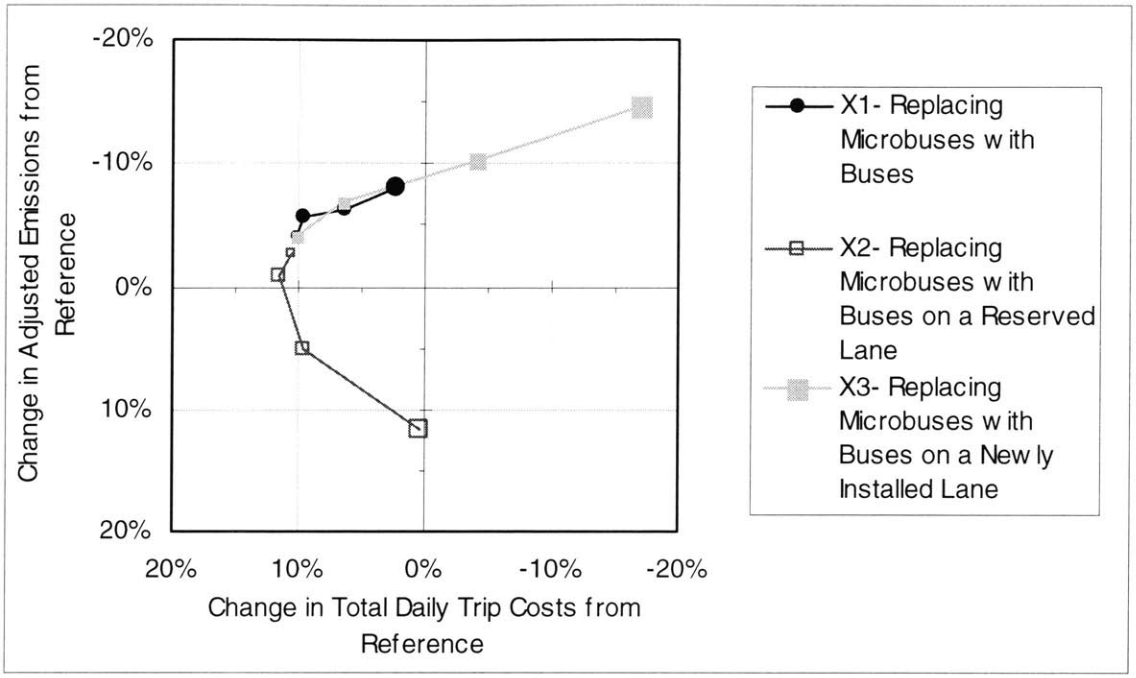
To test the effectiveness of this plan, the corridor model was run using data on the current fare structure for the buses (flat $1.50 pesos) and colectivos ($2.50 to $3.50 pesos depending on distance) and assuming 75% of passenger trips are on public transport modes along a particular corridor. New buses are assumed to meet EPA98 emissions standards while used buses utilize the emission factors previously presented.

The results, in Figure 3-17, show that replacing the microbuses with buses does indeed reduce emissions under all conditions of congestion, but it also reduces mobility by increasing total trip costs (X1). By reserving an existing lane for the new colectivo buses to share with the regular buses, mobility is only slightly better under highly congested conditions while emissions are significantly worse (X2). The best possible option is, as

[66] Based on personal communications with Alejandro Villegas and *La Reforma* newspaper article, "Viajan

expected, to install a new lane for all public transport modes (X3). Under congested conditions, this strategy not only improves emissions but also mobility significantly. However, the cost of such a measure is often prohibitive.

Figure 3-17: Strategies for Replacing Microbuses with Buses



In the analysis of these strategies, it is also important to consider the change in operating revenues and costs for the bus and colectivo fleets. As can be seen in Table 3-10, replacing microbuses with buses has a negative impact on colectivo fleet profit. The negative impact increases with the level of congestion. This loss in operating profit is one of the possible reasons for the reluctance of colectivo owner-operators in participating in such a substitution plan. Other reasons and issues, including the high capital cost of new vehicles, is discussed in Chapter 4.

The two strategies tested (X2 and X3) tend to have a positive impact on colectivo fleet profit. Therefore, these strategies may make SETRAVI's substitution plans more acceptable to colectivo owner-operators. However, these strategies also have a negative

capitalinos en microbuses caducos." 28 March 2001 impact on bus fleet profit because the buses do not have a competitive advantage when sharing the exclusive right-of-way with colectivos.

Table 3-10: Results of Strategies for Replacing Microbuses with Buses

	Change from Original Conditions			
Uncongested Conditions (Corridor LOS A-B)	**Total Trip Costs**	**Adj. Emis-sions**	**Bus Fleet Profit**	**Colectivo Fleet Profit**
X1-Replacing Microbuses with Buses	10.3%	-4.1%	$5,642	-$25,395
X2-Replacing Microbuses with Buses (Reserved Lane)	10.7%	-2.7%	$5,642	-$25,395
X3-Replacing Microbuses with Buses (Newly Installed Lane)	10.3%	-4.1%	$5,642	-$25,395
Fair Conditions (Corridor LOS B-C)				
X1-Replacing Microbuses with Buses	9.6%	-5.7%	-$338	-$42,187
X2-Replacing Microbuses with Buses (Reserved Lane)	11.6%	-0.8%	-$1,782	-$38,742
X3-Replacing Microbuses with Buses (Newly Installed Lane)	6.5%	-6.8%	-$1,782	-$38,742
Congested Conditions (Corridor LOS C-D)				
X1-Replacing Microbuses with Buses	6.4%	-6.4%	-$882	-$58,377
X2-Replacing Microbuses with Buses (Reserved Lane)	9.6%	5.0%	-$6,217	-$37,649
X3-Replacing Microbuses with Buses (Newly Installed Lane)	-4.0%	-10.3%	-$6,217	-$37,649
Highly Congested Conditions (Corridor LOS E-F)				
X1-Replacing Microbuses with Buses	2.4%	-8.1%	-$2,119	-$76,163
X2-Replacing Microbuses with Buses (Reserved Lane)	0.4%	11.6%	-$14,662	-$10,031
X3-Replacing Microbuses with Buses (Newly Installed Lane)	-16.9%	-14.5%	-$14,662	-$10,031

3.10 Conclusions

Very often, people are making a rational decision in choosing colectivos over the less-expensive public bus. They are minimizing their trip costs according to the way they value their time and activities. In many cases, mobility enhancement from the faster speeds of smaller vehicles outweighs the fare premium. The extra congestion they cause is not a typically a factor in mode choice, except indirectly. Fundamentally, the bus requires more of a competitive edge to beat the colectivo; lower fares alone do not appear to be enough. A more effective strategy is to ensure the speed and reliability of bus services by providing an exclusive right-of-way.

Under congested conditions, the average speeds of buses and colectivos drops significantly. The travel speed is a major determinant of the delay time for passengers and thus mobility. As long as colectivos are faster, there may be mobility benefits to switching passengers from buses to colectivos. This again follows the premise that people are minimizing their overall travel cost by patronizing colectivos, as evident by their high mode share in rality. The high colectivo mode share, in turn, is sustained by high frequencies, which reduces the wait time passengers experience. This may explain the observation that many people transfers up to five times between colectivo vehicles and routes to reach their final destination as described by Cervero (1998). The issue of intermodal and intramodal transfers will be address more substantively in Chapter 5.

For the colectivos, the maximum profit per vehicle and for the entire fleet is achieved by operating vehicles with a capacity between 35 and 40. This depends on the ratio between bus and colectivo fares and the operating costs of vehicles of different sizes. However, it may explain why colectivos have evolved from sedans to vans and finally to microbuses as their business became essentailly a fixed-route transit service. As for the bus, the maximum fleet profit is achieved with a fare of $1.75 pesos. This assumes a colectivo fare between $2.50 and $3.50 varying by distance. However, this "optimal" bus fare raises numerous political and social issues and seems to be unaffected by the level of demand or congestion on a corridor.

In sum, the modeling of road-based transportation in Mexico City is a useful exercise to ascertain the positive and negative consequences of various strategies on mobility and emissions along a corridor. This analysis, however, has not addressed the political and regulatory issues involved in such strategies. To this end, the next chapter will explore regulatory models and the political realities associated with public transportation startegies.

Chapter 4. Regulation of Road-Based Public Transportation

4.1 Introduction

In most cities of the developing world, road-based public transport (i.e., buses, vans and the like) is the primary mode of travel. Varying degrees of government regulation control its provision, which in Latin America is usually the role of private organizations or individuals. There are many characteristics of cities that influence the implementation or performance of any regulatory scheme over public transportation. By exploring these factors, it is possible to suggest how regulated competition of public transportation services can be made more effective and sustained in Mexico City.

In the last two decades, several developed countries have undergone a wave of deregulation where public transportation enterprises have been restructured to be more market-driven.[67] Public monopolies have historically been more acceptable, although not necessarily optimal, partly because these countries are wealthy and the buses carry only 5% to 20% of trips in most metropolitan areas. The competition is modest since the market is thin and there is a fear that a private operator might be able to develop a monopoly. Given that the bus mode share is small and the countries are relatively wealthy, governments are better able and more willing to subsidize inefficient bus operations.

In the developing countries of Latin America, by contrast, the risks of a public monopoly (e.g., low efficiency and high costs) are less acceptable and competition in an open market is more attractive. Bus ridership is high and the markets are large. This inherent competition and contestability reduces the fear of a private monopoly. Since buses carry 60 to 80% of urban trips and society's resources are much more limited, the government

[67] For more information about the experiences in North America, Europe and Asia, see Glaister (1997) and Cox et al. (1997).

is less likely to subsidize public transport. Private transportation firms commonly adjust services to optimize market conditions but usually at the expense of socially desirable services.

Overall, the benefits and success of public transport regulations rest on a number of potential tradeoffs summarized below.

- Market agility versus service reliability and stability
- Rate of innovation and implementation versus financial risk
- Specificity of the terms and conditions in the contract between the government and the concessionaire versus flexibility of service
- Socially desirable fares and services versus costs recovery and profit
- Institutional capacity versus legal and administrative costs
- Level of supervision and enforcement versus conflicts of interest and threat of corruption
- Market-driven initiative and competition versus system coherence, integrity, and legibility

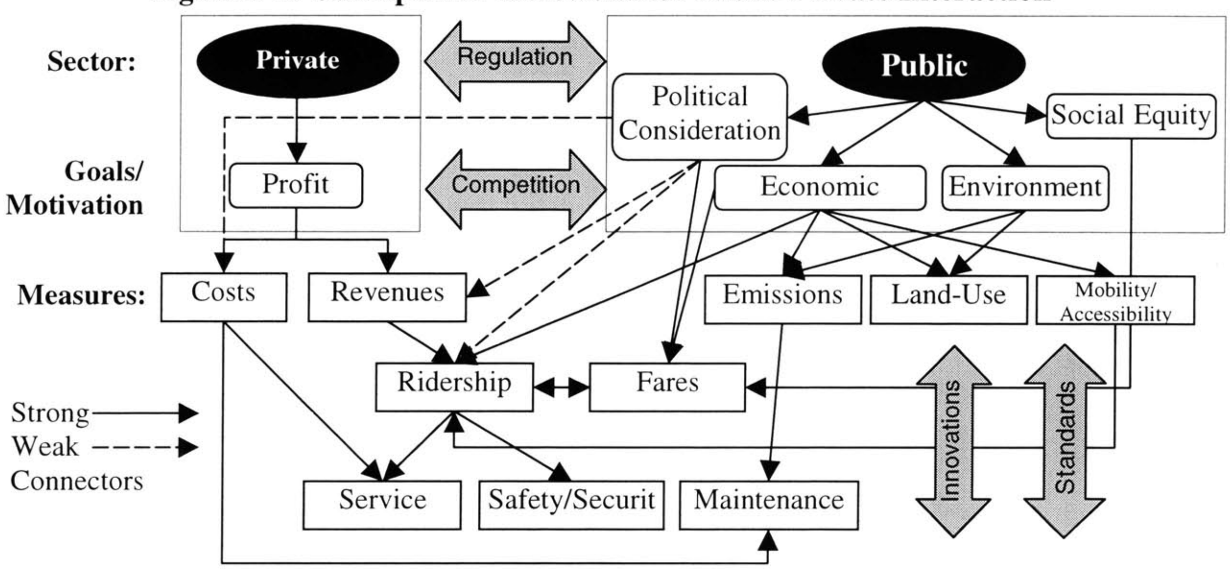
In light of these issues, the prospect of changing the current regulatory system in the developing world can seem like an insurmountable task. The purpose of this chapter is to understand the difficulties associated with regulation of public transportation in Latin America and the developed world. In addition, the chapter concludes with suggested strategies to minimize the negative impacts of regulation while maximizing the potential benefits in a developing world context.

4.2 The Dynamics between the Public and Private Sectors

Public transportation is a vital service with multiple stakeholders and objectives, such as personal mobility, economic development, and air quality improvement. These aims sometimes are conflicting or may be entirely unrealistic, such as solving all air pollution problems by regulating a single mode of transport. Several fundamental questions arise including: how should public transportation be organized and regulated in order to ensure the greatest success of multiple objectives and long-term stability? What are the possible roles of the state in a privately operated environment? These questions are particularly relevant to Mexico City and may be applicable to many other large cities, especially in Latin America.

Figure 4-1 presents a basic framework for understanding the role of regulation and competition in the conflicts between public and private goals in the provision of public services. Solid lines indicate the stronger links while the dashed connectors are weaker links.

Figure 4-1: Conceptual Framework for Public-Private Interaction



In this framework, regulation is the legal domain linking the public and private sectors and is represented by a horizontal block arrow. Similarly, competition is the process of evaluating the importance of the various goals and objectives. In another vein, innovations and standards are processes that cut vertically between measures. For example, a new emissions technology or standard will necessarily change maintenance practices. The motivations for regulations, standards, or innovations include profit, politics, economic development, environment, and equity.

In theory, the effectiveness of any regulatory measures depends on a number of local variables. The variables and issues of importance to Latin America, and Mexico City specifically, will be described in detail later. The premise is that these issues are significantly different from that of the developed world and therefore the form and structure of the regulation should be fundamentally different. In addition, the framework developed is supported by the following general principles observable in most cities of the world.

The general perspectives of the public sector include:

- A long-term focus
- Operating in accordance to the political cycle (i.e. 2 to 6 years typically)
- Multiple stakeholder framework
- A complicated set of goals and objectives that are difficult to measure
- Typically slow and bureaucratic internal processes
- Accountable to the public or representatives of the public
- Typically increases investment in economic downturns

In contrast, the general perspectives of the private sector include:

- How to turn a profit in the short to medium-term
- Operating in accordance with the business cycle necessitating quick decisions
- Accountable to stockholders and investors, but not necessarily the public
- Increase investment when the economy is running well

It is also possible to imagine hybrid arrangements where the public and private domains overlap. These public/private options may be able to align a larger set of objectives and subsequently the measures beneath them. There can be balances that try to optimize both the positive and negative aspects of public and private provision. Examples include the U.S. Postal Service, which moves mail in competition with numerous private companies.

4.3 Models of Transit Regulation and Organization

Table 4-1 presents the spectrum of regulatory and organizational models for public transportation services. First, each function of providing public transportation service is broken down and assigned to the public sector, private sector, or both. Second, a list of general regulations is listed and designated as existing or non-existing in each of the regulatory models. Lastly, several general characteristics of each regulatory model are rated and compared. Theoretically, the regulatory environment can be viewed as a continuum bound on one side by a free and open market, and on the other by a non-competitive public monopoly. The following sections briefly describe the set of options detailed in Table 4-1.

4.3.1 Unregulated or Deregulated Market

The rationale for this structure is that competition generally promotes cost efficiency, innovation and greater sensitivity to user needs. However, a free market can also lead to chaotic, inconsistent, and uncoordinated bus operations. Other concerns under this *laissez faire* attitude are safety standards, environmental impact, equity, and minimum levels of service. It is unlikely that socially desirable services, such as early morning or off-peak, would be provided by the private sector without economic incentives to do so.

Some observers believe that bus markets are not characterized by substantial economies of scale or scope and that they may be among the most contestable.[68] Nevertheless, without competition a private firm will be driven by profit-motive to abuse market-power by raising fares, reducing the quality or quantity of service, or instituting predatory practices. This has been observed in numerous cities and provides a level of justification for some regulation.

[68] Goméz-Ibáñez and Meyer (1997)

Table 4-1: Summary of Regulatory Models for Public Transportation

FUNCTIONS:	Unregulated/ Open Market	Regulated Competition/ Tendering	Threatened Competition	Private Monopoly	Contract Management	Performance Agreement	Public Monopoly
Financing	Private	Private	Private	Private	Private	Public	Public
Ownership of Infrastructure	Private	Private	Private	Private	Private/Public	Public	Public
Ownership of Rolling Stock	Private	Private	Private	Private	Private/Public	Public	Public
Planning/Service Definition	Private	Private/Public	Private/Public	Private/Public	Public	Public	Public
Fare Setting	Private	Private/Public	Private/Public	Private/Public	Public	Public	Public
Revenue Collection	Private	Private	Private	Private	Private/Public	Public	Public
Labor Contract Management	Private	Private	Private	Private	Private/Public	Public	Public
Operations	Private	Private	Private	Private	Private	Private	Public
Maintenance	Private	Private	Private	Private	Private	Private	Public
REGULATIONS:							
Safety	Y/N	Y	Y	Y	Y	Y	Y
Socially-Desirable Fares or Service	Y/N	Y/N	Y/N	Y	Y	Y	Y
Environmental Criteria	Y/N	Y	Y	Y	Y	Y	Y
Vehicles Specifications	N	Y/N	Y/N	Y/N	Y	Y	Y
Entry to the System	N	Y	Y/N	Y	Y	Y	Y
Employment Standards	Y/N	Y/N	Y/N	Y/N	Y/N	Y/N	Y
Level of Service	N	Y/N	Y/N	Y/N	Y	Y	Y
Level of Regulation	Minimal	Low	Contractual	High	Contractual	High	High
GENERAL CHARACTERISTICS:							
Decision-Making	Atomized			Centralized			Centralized
Operators/Service Providers	Numerous	One to Few	One	One	Usually One	Usually One	One
Informal Sector	May coexist	May coexist	May coexist	Suppressed	Suppressed	Suppressed	Suppressed
Vehicle Capacity	Lower			Higher	Higher	Higher	Higher
System Stability	Low	Medium	Medium	High	Medium	Medium	High

Adapted from Salvucci, et al. (1997) and Gwilliam (1997)

There is also a set of concerns if competition is intense under this unregulated environment.[3] First, stability and reliability of services is crucial to regular passengers, but intense competition may drive frequent changes to services in order to most efficiently serve the demand. Second, there are few incentives for firms to initiate coordination and integration of services because they may be unable to capture the full commercial benefits; it may even threaten their own profitability. Third, price competition may be limited because most passengers seem to be so sensitive to waiting times that they take the first bus that appears. Finally, there are notorious practices (such as headrunning and blocking) and other externalities where there is intense competition on the road.

4.3.2 Public Monopoly

On the other extreme is the public monopoly option. Most experts would agree that it is more conducive to the provision of an integrated, safe, and comprehensive service with an aim of maximizing social benefit. Despite being the convention in most of North America and Europe, state-controlled monopolies are also vulnerable to poor service, excessive labor costs, perverse management incentives and a lack of entrepreneurial dynamism.[1] In fact, concerns over costs and rising subsidies were the primary reasons for the institution of competitive tendering of London's local bus services starting in 1986, as will be described later.

When a public agency has the central responsibility for planning, operating, and managing a transit service and it is the only operator, certain tendencies can occur such as a lack of financial efficiency, a lack of responsiveness to changes in the environment or travel demand, a lack of service quality, and high vulnerability to media scrutiny.[69] For this and other reasons, developing countries have tended to avoid this organizational model. However, this structure is highly stable in North America because of the small

[69] Lecture given by Nigel H.M. Wilson, MIT Professor of Civil and Environmental Engineering and Engineering Systems, on 14 September 2000.

role of the national government in local public transport, the resistance of local organized labor to change, and protracted policy debates.[70]

4.3.3 Intermediate Options

Another set of structures, detailed in *Table 4.1,* lies between public monopoly and open market. These intermediate models usually involve private operators with some degree of public regulation through a commission, staff oversight, or contractual terms of fares, entry, or a number of other aspects.[71] The British public transport reforms and London's competitive tendering process beginning in 1986 are the most notable examples of intermediate options.

4.3.4 British Deregulation

Political changes in Britain in the early 1980s brought about a pioneering experiment of two regulatory systems that are thoroughly described in the literature. The premise was that a move towards greater private sector participation would create competition, thereby improving system cost efficiency and innovation. There was also a desire to eliminate public subsidy and internal cross-subsidies.

Outside of London, a deregulated two-tier system was devised, (1) commercial services and (2) socially-desirable services. Private bus operators were free to design the routes they wished to serve and set their own fares, subject only to regulations for basic vehicle and driver safety. Public agencies were corporatized and then fully privatized. Most observers agree that the end results were significant cost reductions but limited competition in certain markets due to the significant advantages enjoyed by the incumbents. The competition exists on frequency rather than price. Some innovations were introduced such as smaller buses, which is consistent with a strategy of increased frequency.

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[70] Salvucci et al. (1997)
[71] Goméz-Ibáñez and Meyer (1997)

In London, however, the risks were much greater and traffic congestion more severe. Therefore, the approach was less drastic and did not include total deregulation. The local public authorities retained control over route design and fares but were forced to tender all services to private firms in a progressive and competitive process. The public domain over bus services effectively shrank by 5% per annum, which just about matched the rate of attrition in London Buses (LBL).[72] The full transition took about 7-8 years under a complex arrangement that maintained the integrity of the network in terms of fares, service planning, public information, and system identity. The end results were similar reductions in cost and subsidies as compared to the rest of Britain but without some of the less desirable side effects.

The advantages of London's approach are as follow: it maintained fare setting and network design under public control; service stability was considerably better; and the public authority retained control over high level planning, infrastructure investments, vehicle specifications, and quality. Most observers agree that the tendering process was more successful because it avoids the resource waste of competition on the road, offers the opportunity to balance fares and services, and avoids the loss of consumer confidence associated with unreliable services.[73] The disadvantages include a large disconnect between planner and operators, a slow rate of change and innovation compared with deregulation, and difficult conflicts of interest for LBL.

The lessons of Britain and London's experiences are somewhat arguable. There was a clear affirmation of cost reductions through privatization but mainly through greater work rule flexibility under private firms, smaller maintenance and administrative staffs, and lower salaries and benefits, rather than significant process and technological innovations. Since the British reforms, other cities around the world have instituted competitive

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[72] Lecture given by Nigel H.M. Wilson, MIT Professor of Civil and Environmental Engineering and Engineering Systems, on 14 September 2000.
[73] Mackie, et. al. (1995, p. 317) as cited in Goméz-Ibáñez and Meyer (1997)

tendering. Copenhagen, for example, has implemented a similar plan with policy and planning under public control while operations are competitively tendered.

4.4 Issues in Latin America and the Developing World

The application of various theoretical regulatory models or examples from the developed world to Latin American cities, such as Mexico City, is considered next. The political history of Latin America is also germane to understanding these models and is briefly described later in the text. The following is a list of the most significant issues affecting the provision and regulation of public transportation in Latin American cities and mostly applicable to the rest of the developing world.

4.4.1 Factors Affecting the Regulation of Public Transport

1. High External Costs

In the largest cities of Latin America, it is common to observe very high levels of congestion due to a lack of infrastructure and high traffic volumes. This results in unnecessary but real costs to the economy in the form of wasted time and environmental problems. Air and noise pollution are generally more severe than in the urban areas of the developed world. In the case of Mexico City and some other cities, the topographic conditions or altitude exacerbates the environmental problems. Diesel buses are sometimes cited for being large contributors to these problems while at the same time attracting a small portion of choice riders that would be using higher-polluting private vehicles otherwise.

2. Heavier Reliance on Public Transport

The rubber-tire public transportation typically captures more than 60% of all motorized trips in Latin American cities. This is even the case in the handful of Latin American cities with a metro system, namely São Paulo, Rio de Janeiro, Santiago de Chile, Buenos Aires, and Mexico City. Particularly for the poor, who tend to live in the periphery of metropolitan regions but work within central cities, it is the primary mode of transportation. The rich tend to live closer to the city centers. This is the inverse of the pattern observed in North American cities and it results in higher commuting times for poorer people who rarely own vehicles.

3. High Unemployment

Unemployment and underemployment rates of 20-30% are common in Latin American countries. It often drives the rural poor to seek jobs in the cities.

4. Informal Transportation Sector

There is a greater presence of informal transportation (i.e., jitneys and microbuses) that reacts more quickly to changes in demand and provides better service to the periphery of cities. A highly atomized and open public transportation system with few barriers to entry also tends to be best suited for absorbing the unemployed and rural migrants. It is also common to see a greater variety of vehicle sizes and types in informal transit in Latin America. These factors have a significant impact on the operations and organization of public transportation.

5. Current Regulatory Environment

It is far more common in Latin America to observe unregulated or loosely regulated environments for public transportation. How does starting from this condition, as opposed to a public monopoly in the developed world affect the implementation and approach of a new regulatory system? This is likely to significantly impact the approach because there will be significant resistance from current stakeholders to new regulations that change the current equilibrium against their favor.

6. Institutions and Politics

In general, there is greater political instability and institutional tensions than in the developed world. This has an obvious impact on the stability of service provided by the public sector and the enforcement of regulations.

7. Social Needs

Other greater social needs and problems such as housing, famine, or health compete for scarce government resources. Public transportation is therefore a relatively low priority for government resources under such conditions.

8. Fares

Fare evasion is a pervasive problem in some Latin American cities. There is also significant political pressure to maintain fares low for social reasons, which hinders the ability of the operator to renovate or re-capitalize the equipment.

9. Professional Culture and Corruption

Corruption in all levels of government and industry is an ever-present problem. Most of it is in the form of small bribes to circumvent certain laws and regulations. The Latin American voting public is also generally accepting of some level of corruption in national governments. There are also weaker legal authorities to stamp out corruption, but there is some level of self-regulation. For instance, in the private sector, some enterprises and route associations act as cartels. In an expanding market, it is favorable for operators to set up cartel-like organizations such as the *sindicatos* in Latin America. Its role is to restrict the entry of new operators in the business and to distribute among the cartel members the shares of the protected market. This reduced competition often degrades the level of service. Another key role of the organization is to enforce regulations agreed upon by its members since individually, each operators could reap huge rewards by cheating.[74]

10. Labor Management and Administrative Costs

Management problems and costs of public transportation firms typically increase with the size of the organization. This factor forces down the size of organizations in Latin America. There are also other significant barriers such as the high cost of insurance.

4.4.2 Factors Affecting Mobility

The following are other issues related to mobility and transportation prevalent in the developing world:[75]

- High percentage of population in urban areas and continued migration from rural areas
- Systematic changes on many fronts (i.e. income, land-uses, institutions, etc.)
- High share of trips (10-30%) by non-motorized transportation (walking and biking)
- Travel demand far exceeds supply from transportation facilities

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[74] Darbéra (1993)

[75] Based on presentation by Prof. Ralph Gakenheimer, MIT, on 3 November 2000.

- Higher urban densities
- Private vehicles have incompatible characteristics with pre-motorized cities (i.e. living densities, street space, parking supply, mixed land-uses)
- Stronger land-use/transportation relationship than in the developed world
- Road vehicles have wide differences in performance such as speed, acceleration, stopping characteristics (i.e., two-wheelers versus automobiles)
- Inadequate street and highway maintenance
- Relative low quality and scarcity of data
- Rapid rates of motorization (5-10% p.a.) and varying levels of motorization (60-600 vehicles per 1000 inhabitants)
- Automobile drivers are wealthy and have greater political power
- Low level of political support for environmental quality even as problems tend to be worse
- Driver discipline on the road and law enforcement a problem

4.4.3 Factors Affecting Land-Use and Transportation

In particular, there are significant differences in land-use patterns and transportation in the developing world as compared to the developed world. Table 4-2 provides a side-by-side comparison of some of these: [76]

Table 4-2: Comparison of Land-Use and Transportation Issues

Characteristic:	**Developed Countries**	**Developing Countries**
Demographic growth	Slow	Rapid
Motorization (level, rate)	Fully, slow	Low/partial, rapid
Highway system	Fully developed	Less Developed
Land-use authority	Enforced	Wide range of authority
Environmental concern	High	Low but rising in some places

[76] Based on presentation by Ralph Gakenheimer, Professor of Civil and Environmental Engineering and Urban Studies at MIT, on 3 November 2000.

4.5 Relevant Political History in Latin America

Latin America is a large region that extends from Mexico on the north to the southern tip of South America and encompasses a wide range of socio-economic conditions. In general, however, the countries in this region can be categorized as lower-income in terms of gross domestic product per capita, typically speak a romance language (predominately Spanish) and share other cultural traits. There are other significant commonalities in the region including a history of political upheaval, economic volatility, and significant social problems.

Despite a wave of nationalization of private companies after the Second World War, countries in Latin America have had a long history of private sector participation in all sectors including public transportation. In the 1970s, the political environment began to change from command-and-control to more market-based or "neo-liberal" policies promoting economic development and efficiency. Most notably, after General Pinochet came to power in Chile after a military coup in 1973, he was determined to rid Chile of socialism and to reassert the primacy of free-market principles in all sectors of the country's economy. Less dramatically, neo-liberals came to power or political prominence in the 1980s in other large countries of the region. For example, the dominant political party in Mexico until recently (the PRI) formally adopted a neo-liberal platform in the presidential election of 1982. The hyperinflation of the 1980s also deeply affected the largest economies of the region and pushed sentiments further towards neo-liberalism. The current political environment in the region continues to favor a large role for the private sector.

Opponents of neo-liberal thinking assert that privatization can increase efficiency in industries such as steel but not so definitively for sectors closer to natural monopolies such as utilities and transportation. Some hold the opinion that urban transport is a sector where "the free interaction of market forces leads to an unstable equilibrium with wide over-capacity."[77] Other concerns include socio-economic inequities exacerbated by neo-

[77] Darbéra (1993)

liberal policies, a reduction in research and development as most of it is done by the state, and a general fear of the withering away of the role of the state from roads and ports, to health, to police and security.

There are other unique complications to the role of the private sector in Latin America. Family firms or "grupos", especially in the construction industry, are a long-established form of the private sector that continues to wield tremendous power. These private firms can have a wide scope of business interests and dealings not typically open to public scrutiny. Even after the first wave of privatization under neo-liberalism, many of these firms continued to receive government favors and subsidies sustaining this peculiar sector. This reflects the government's need to make alliances with powerful private players to ensure economic and political stability. In a sense, some argue that there is still a need to privatize the private sector, as these firms do not fit the conventional model of public corporations and can be sources of inefficiency and inertia.

4.6 Review of Major Latin American Public Transport Systems

The attached Tables 4.3a and 4.3b provide a summary of the road-based public transport systems of major Latin American cities using the designation and structure developed in Table 4-1. The cities described include:

- Buenos Aires, Argentina
- Montevideo, Uruguay
- Porto Alegre, Brazil
- Curitiba, Brazil
- São Paulo, Brazil
- Mexico City, Mexico
- Santiago, Chile

Table 4-3a: Survey of Road-Based Transit Systems in Major Latin American Cities

	Buenos Aires	Montevideo	Porto Alegre	Curitiba
Current system	Contracting/Concession	Contracting/Concession	Contracting/Concession	Contracting/Concession
Previous system	Open market/privatized	Open market/privatized	Open market/privatized	Open market/privatized
Public Authority, employees, level of government (began)	CNRT, 400, federal (1997)	Division of Transit and Transportation, <100, municipal (1989)	SMT, municipal (1989)	URBS and IPPUC, >300, municipal (1973)
Private Entity	About 100 route associations (colectivos) made up of individual owner-operators	5 cooperatives with worker-shareholders (CUTSA, UCOT, COETC, RAINCOOP, COMESA)	16 providers	10 providers with long-term concessions controlled by URBS
Number of Buses	10,000	1,500	1,500	1,600
Financing/Ownership of Vehicles	Private: buses must be replaced after 10 years	Public/Private: captured in formula, previously leased buses from government bank	Public/Private	Public/Private: depreciation captured in formula, operators usually lease
Financing/Ownership of Infrastructure	Public	Public: planned 20 new terminals and 4600 bus stops	Public	Public/Private: operators own some facilities
Planning/Service Definition	Public	Public	Public	Public: IPPUC city planning agency
Fare Policy	Public: Fares tied to inflation, quality index measures, and political increases	Public: "magic formula" with social and financial goals	Public	Public: formula used to achieve social policies and financial goal
Revenue Collection/Remuneration	Private: operational subsidies and shared revenue within cooperatives	Public: based on "magic formula" of revenue per passenger for each operator	Public/Private ("Compensation Chamber" by operator): per-kilometer by type of vehicle	Public (cost plus 8-10% profit from a "Compensation Chamber"): per-kilometer by type of vehicle (recalculated annually)
Labor Contract Management	Private	Public: government contract with union	Public: government contract with union	Public: government contract with union
Licensing/Operations	Public: Licensing of operating rights, safety, and environmental standards	10-year permits to numerous operators on the same routes	Public	Public
Maintenance	Public/Private	Private: vehicles and facilities	Public: bus inspection every 45 days	Private
Customer Service	Public: quality-index, toll-free number	Private: incentive to increase ridership		Public: extensive customer satisfaction surveys
Safety Standards	Public	Public	Public: bus inspection every 45 days	Public
Environmental Standards	Public: random inspections	Public	Public: bus inspection every 45 days	Public: controlled vehicle specifications
Trend	Companies and individual operators are consolidating	Decreasing ridership (2% p.a.)	Plans for AVL and APC	
Socially-beneficial Service Requirements	Some all-night and low-ridership service	Self-reported social fares (to seniors and low-income) paid back as subsidy and verified by independent auditing	Seniors, persons with disabilities, and students	Seniors, persons with disabilities, uniformed public employees, and students
Coordination	Low, some bus-rail competition	Low, some competition among operators on the road for passengers		
Informal Sector Presence	Small but growing			
Sources:	*Lee (1999), Sant'Anna (2000), Salvucci (1997)*	*Lee (1999), Sant'Anna (2000)*	*Lee (1999), Sant'Anna (2000)*	*Lee (1999), Sant'Anna (2000)*

Table 4-3b: Survey of Road-Based Transit Systems in Major Latin American Cities

	São Paulo	Mexico City	Santiago
Current system	Concessions (2 Levels)	Open market/privatized	Concessions (1991)
Previous system	Open market/privatized	Public Monopoly (Ruta-1000 1981-95)	Open market/privatized (1979-1991)
Public Authority, employees, level of government (began)	EMTU, state (1980s) & SPTrans, municipal (1980s)	SCT, federal & COMETRAVI, metropolitan (1980s)	CTIIT, federal
Private Entity	60 companies for local service and 54 for regional	Hundreds of colectivo route associations with tens of thousands of operators in the metropolitan region	Numerous firms and operators
Number of Buses	>3,500 (state) & >11,000 (city)	2,500 (buses) & >50,000 (microbuses)	>9,000
Financing/Ownership of Vehicles	Private	Publlic and Private separately	Private
Financing/Ownership of Infrastructure	Public	Public	Public/Private
Planning/Service Definition	Public: independently by EMTU and SPTrans	Public and Private (route associations) separately	Public
Fare Policy	Public: some of the highest in Latin America, subsidized by some employers	Public: set by SCT and other bodies	Private: set according to the concessioning agreement and adjusted for variation in costs
Revenue Collection/Remuneration	Public ("Compensation Chamber")	Private: no subsidies provided	Private
Labor Contract Management		Private	
Licensing/Operations	Public	Public: controlled by SCT but an estimated 50% of microbuses are unlicensed	Public
Maintenance	Private	Private	Private
Customer Service	Publically administered customer surveys (state) to be replaced by inspection and independent surveys and annual TQM program (city)	Private	Private
Safety Standards	Public	Private	Public
Environmental Standards	Public	Private	Public
Trend	Emphasis on rail expansion, state's regional plan	The public bus agency continues to decline (<800 buses)	
Socially-beneficial Service Requirements	Seniors, persons with disabilities, and students	None	Discounts for students
Coordination		Microbuses are so ubiquitous and frequent that no coordination is needed in peak hours	
Informal Sector Presence	Small but growing	High, 60% of all trips	
Sources:	*Lee (1999), Sant'Anna (2000)*	*COMETRAVI (1999), Zagras et al. (2000)*	*Darbera (1993), Sant'Anna (2000), Gomez-Ibanez & Meyer (1997)*

4.6.1 Characterizations

It is important to note that these cities vary greatly in land area and population. However, certain lessons may transcend the differences between them. Curitiba, for instance, is regarded as a model for integrated land-use and bus rapid transit in both the developed and the developing world. Santiago has been a frontrunner in deregulation of public transport and more recently in competitively contracting public transportation services.

Two other cities that recently underwent significant changes are Buenos Aires and Quito. The public transportation system in Buenos Aires has been described as an example of the ability of private sector entrepreneurship, cost consciousness and customer-orientation to produce a reasonably high-quality, ubiquitous and affordable system within a policy framework of government-established service levels and fares.[78] Prior to reforms, public satisfaction with the public transport system was very low and fare evasion was commonplace.

Quito has experienced severe air pollution problems caused by increasing automobile traffic and poor-running diesel engines in the oxygen-poor high altitude. By the early 1990s, this had begun to impact public health and even the facades of historic buildings. A relatively new bus rapid transit system operated by the municipality uses highly-efficient electric trolley-buses on 11.2 kilometers of exclusive right-of-way and replaces the old and dilapidated system of private bus operators which, in 1992, had an average bus age of 17 years, with some as old as 35. The operating costs of the new system are covered without subsidies and the capital costs were financed with an international loan. Other features of the system include clear signage and color-coded vehicles. During the planning stages of the new system, the municipal government created a single regional agency responsible for transportation and development, UPGT, a well-staffed and progressive organization.[79]

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[78] Salvucci (1997)
[79] Arias and Wright (1999)

Arias and Wright (1999) comment that convincing the private bus operators and the labor unions in Quito to give away the most profitable transit route was extremely difficult. While many elements of the trolley system are contracted out and the feeder system is still private, many small bus operators suffered. A weeklong strike paralyzed the city and only ended with military intervention. Despite extreme economic hardship, a recent currency crisis, political turmoil, and natural disasters, a successful system was implemented and is operating.

In the largest cities investigated, the rising number of clandestine and unregistered public transport vehicles may be an indication that the formal bus service undeserves its residents.[80] Seeing this, the municipal government of São Paulo enacted a law in October of 1999 authorizing the complementary public transportation service in certain areas of the city in the form of "kombis" or 8 to 10 passenger vans. By the end of 1999, the São Paulo municipal public transport agency had registered over 4,000 of these vehicles covered by the new law. An estimate from February 2000 counted 14,000 to 18,000 kombis or *peruas* circulating the city, each carrying an average of about 150 passengers daily yielding a total of 2 million passengers per day.

Despite being an illegal business for many years, the jitney operators in São Paulo have long been organized into a syndicate, called "Sindilotação", which plans, manages, and controls the routes. The frequency of the jitney service on these routes is controlled by the syndicate to guarantee its members a certain volume of passenger per vehicle. The syndicate also enforces the routes to prevent the operation of non-affiliated vans. The vans are typically equipped with communication radios and the routes are controlled by dispatchers and enforcement personnel at stops to control the headway between vehicles and the collection of fares. In this manner, the syndicate in São Paulo is better run than many public transport agencies. The president of the Sindilotação says that jitney services in São Paulo began in the 1960s when kombis began servicing peripheral areas not covered by the bus companies. The first syndicate of "perueiros" or operators began

[80] Viação Ilimitada: Ônibus das Cidades Brasileiras. Anisio Brasileiro, Etienne Henry, et. al.; Cultura Editores Associados, 1999.

in 1981 and by 1987 had more than 1,000 associates. The organizations representing the bus operators in São Paulo, *Transurb*, admits that bus driver strikes in the early 1990s opened the way for perueiros which until then only filled in gaps in public bus service. The poor operation of buses at that time allowed the perueiros to expand service and attract new riders. To enter the syndicate an operator must purchase a "space", which costs between US$3,000 and US$10,000 depending on the quality of the route. An operator usually earns between US$7 and US$30 per day. The vehicles also vary from 20-year-old kombis to brand new microbuses costing US$25,000. To enjoy the other services of the syndicate, a member must also pay a monthly fee.

The general trend from most of the cities shows an increase in tendering or concessioning of transportation services with time. All of the cities investigated have some form of contracted public transportation service. The city closest to a true free market structure is Santiago, where all road-based public transport is private and fares are competitively set during the awarding of concessions. In all other cities, fares are set by public entities. Partnerships between public and private entities are common in the financing of vehicles. Particularly in the Brazilian cities, revenue collection and remuneration is also a public/private function. A "compensation chamber" collects all revenues and are redistributed to private providers according to specific formulas. The remuneration is by kilometer-traveled or passenger kilometer-traveled. Increasingly, quality of service measures are also factors in remuneration. In Buenos Aires, public surveys conducted periodically have a direct implication on the rate of compensation for contracted companies. This extra level of regulation and public scrutiny has led to a consolidation of companies.

Finally, it is important to note that of the cities investigated, Buenos Aires, Santiago, São Paulo, and Mexico City have metro systems. These are also the largest cities of the group. The integration of surface and sub-surface modes is handled somewhat differently in each of these cities because of different regulatory environments. Nonetheless, in all of these cities the government is the provider of mainline high-capacity services, namely the metro, while the private sector is predominant in low and medium-capacity services. The success of having private operators feed metro stations has been variable.

4.6.2 Institutional Typologies

Allen (1990) identifies four institutional typologies observable in Latin America presently and in the recent past. Their differences suggest how the institutional structure may lead to different distributions of costs and benefits among various sectors of society:

a. Deregulated Environment

In cities where a regulated or publicly operated transportation service was once provided, deregulation is an option. This is best seen in Chile with the multiple-phase deregulation of Santiago's bus system starting in 1979, then 1983, and then again in the late 1980s. In essence, it eliminated the distinctions between formal and informal buses with fewer barriers to entry and open-market fares and service provision.

b. Semi-Regulated Environment

This is sometimes characterized by the coexistence of a prosperous private sector and problematic public sector as in Bogotá in the early 1990s. Mexico City until the mid-1990s also belonged in this category. The public bus company, Ruta-100, experienced a precipitous decline since the 1980s and finally went bankrupt in 1995 mostly due to competition with private microbuses. The current bus network in Mexico City is a fraction of the size it once was and is operated by both the DF government (RTP system) and a handful of private companies with concessions.

c. Government Coordinated Transportation

This type consists of high levels of government control over public transport modes. It is characteristic of some of the largest cities of Latin America, especially those with a metro system. In São Paulo, the city and state government currently operate separate bus companies and the metro. The creation of Ruta-100 in the early 1980s in Mexico City was an attempt by the government to manage all bus services. Over the course of several years, the government upgraded the aging fleet of urban buses only to then return all bus services to private operators once again in 1995. Since collapsing and being reorganized, ridership and fleet size of the Ruta-100 has declined to less than 10% of what they were at their peak in the 1980s.

d. Large Role for Informal Operators

This type is characterized by the persistence of informal providers of public transportation despite government efforts to incorporate them into the legal framework. It is important to note from the observation that the informal sector is only prevalent in those cities where the formal transit system is not functioning well. Cervero (1998) characterizes Mexico City's large colectivo sector as an adaptive and efficient market response to the local needs and conditions. Indeed, Mexico City is the best example of a large jitney sector although the colectivos have become increasingly more formal in the last decade. The growth of informal transit in other Latin American cities, such as São Paulo and Rio de Janeiro, has alerted government and public transportation officials to the possibility of a similar decline in metro and bus ridership due to competition.

4.7 Strategies and Best Practices

In setting up a regulatory environment, the essence of the problem are exemplified by the following questions— How can regulations be made most effective in achieving multiple objectives, such as environment and mobility in Mexico City? For instance, how can the entrepreneurial drive of individual owner-operators be harnessed along with the economies of scale, scope or density of a large company without incurring the inefficiencies of a monopoly? Additionally, how can a regulated environment for public transport be created and sustained over time?

In light of these questions, four principles are used to organize strategies and best practices related to the regulation of public transport in Mexico City— (1) improving regulatory implementability or acceptability by reducing stakeholder resistance, (2) enhancing the long-term sustainability and robustness of a regulatory scheme, (3) optimizing operations in terms of costs and level of service, and (4) advancing both environmental (i.e. reducing emissions) and mobility objectives of a regulatory environment. Several of the following strategies are described in the literature. Others were identified by the author or through interviews with transport economists at the Inter-American Development Bank.[81] The success of these approaches ultimately depends on the local context and conditions of urban transportation.

4.7.1 Improving Acceptability and Implementation

Minimizing the number of potential losers, while maximizing the number of those who may benefit, maximizes the likelihood of acceptability and long-term sustainability. The implementation of any new and comprehensive regulatory environment inevitably creates new losers and winners by upsetting the current equilibrium. If possible, a system should achieve Pareto optimum where the total welfare cannot be improved any further by redistributing the costs and benefits. An analysis of the current and potential stakeholders, as described in Section 2.2.3, is therefore essential. The following is a summary of key stakeholders:[82]

- A critical mass of the existing owners and drivers operating the current system needs to see the advantages of a new system or be attracted by economic incentives to ensure successful implementation.
- The users or customers of the current system need to support a regulatory change. If the level of service is already high, the users must be at least indifferent to regulatory changes that would affect service quality. Their active participation is also essential in gathering political support, especially under a democratic government.
- The political interests aligned behind the current system must be appeased by incentives or converted by stronger political interests for a new system to be adopted and supported by the legislature.
- Government and administrative staff will need training to ensure the proper implementation and continuity of the system, especially after short-term consultants have left the scene.

[81] Based on interviews with Matthew Jordan-Tank and Charles L. Wright, Transport Economists at the Inter-American-Development Bank, in July of 2000.
[82] Ibid.

- The government agencies and offices leading the effort for the new system must have the political support of higher authorities, such as the federal government, to overcome initial barriers.
- Environmental organizations and interest groups should be natural allies to regulatory reform that directly or indirectly reduce vehicle emissions. Their active support is potentially useful in the planning and implementation stages.
- Other parties providing financial or technical support to the process (e.g. bilateral or multilateral development banks, equipment suppliers, national banks) should be coordinated to ensure the most effective effort in achieving common goals.

The introduction of a new regulatory scheme should be a gradual and public process to allow for negotiation and coalition building. To demonstrate this point, one only needs to contrast London's gradual transition to competitive tendering with the abrupt inception and collapse of Ruta-100 in 1981 and 1995, respectively. The negative impacts of such changes were much more profound in Mexico City. Experiences from various cities in the world suggest that 3 to 5 years is a minimum transition time, but preferably longer. An example of such an incremental measure is the introduction new buses or vehicles, which typically is contractually required of private operators in exclusive franchises. The introduction should follow a simple incremental schedule dictating the percentage of the fleet at every year of the contract to be replaced or an overall average age of the fleet.

Restructuring can serve as a resetting mechanism to address some of the chronic ills of a public transportation system. In order to maximize the potential benefit, an implementation plan must seize any window of opportunity by addressing immediate problems and public complaints as quickly as possible. By doing so, the governing agency can build on good faith to be used towards larger, long-term problems. This was the lesson from the reorganization of the bus and rail systems in Buenos Aires where overstaffing and rampant fare evasion was drastically reduced in a very short time.[83] In the case of Mexico City, restructuring can serve as an opportunity to address the chief

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[83] Salvucci et al. (1997)

complaints of users, such as reducing multiple fare payments for transfers by integrating fares between the government-operated modes and colectivos that comply with regulations.

Minimizing the time lag between higher fares and service quality improvements is another key implementation strategy. Without a direct connection between fare increases and service improvements, the system becomes vulnerable to ridership decline and even revolt. In Sri Lanka, for example, fares were raised in anticipation of an investment in bus transportation service quality resulting in public rebellion.[84] Another graphic example comes from the Ciudad de Guatemala from the spring of 2000 where, in response to intense pressure from private operators who were threatening to discontinue lease payments on new buses loaned by the municipal government, the mayor decided to allow fares to increase by 50% and deregulated the fares for the higher-capacity buses. This resulted in violent riots and the overturning of the mayor's decision by the federal government because of the public protest.[85] Along the same lines, one should minimize the lead-time between award of service in the case of a competitively contracted process and the service start.

Developing two-way public-private partnerships may also facilitate planning and implementation. As described in Buenos Aires, a delicate balance can be struck between public and private objectives. Moreover, in Japan and Hong Kong, where it is common for transportation agencies to be partially owned by the state and private corporations or investors, public-private partnerships involved shared ownership and risks. This has a direct impact on the goals and motivations of the agency. Another example is Curitiba and the special relationship it developed with the bus supplier of its renowned integrated transit system, Volvo.

The procurement process for competitive concessioning of routes should use a two-step process— a qualification phase and a bid phase. The experience of Buenos Aires is a

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[84] Harvard University, Kennedy School of Government Case (CR1-97-1377.0), 1997.
[85] Based on interview with Matthew Jordan-Tank, July 2000.

good example of this "two-envelope" process. The bidder or consortium that offers the lowest price or fare while meeting all performance and quality criteria (as determined in the first phase) should be awarded the concession. Criteria should also be established to allow the governing agency to award the concession to the next highest ranked and pre-qualified consortium.

4.7.2 Enhancing Long-Term Sustainability

A new regulatory system can be improved in the long-term by fostering a local professional base to maximize participation of qualified bidders in procurement processes. This can be achieved by preserving some local ownership and management of key projects. Often it is the case in developing world that an Asian, European, or North American company is able to sell technology with little local participation by the governing agency or companies that will actually operate and maintain the system. An active local base of professionals and firms can also increase competition during bidding and reduce the possibility of harmful price collusion.

Competition should be viewed as a biological phenomenon that must be grown and maintained. In this manner, an "organic" regulatory system should be better able to respond to shocks from economic or political crises, grow with the level of competition, and adjust to balance other critical parameters.[86] The lifecycle of a regulatory scheme should be considered from inception, to implementation, to maturity. The essential element of this "living" concept is that by designing flexibility to allow for unforeseen circumstances without compromising the integrity of the process, a contract is not soon obsolete. In this manner, the chance of costly and contentious ex-post renegotiation of service contracts is minimized.

For example, a well-designed regulatory system for urban buses must include enough economic incentives to encourage private investments in fleet renovation while allowing sanctions to be imposed by the regulating agency when contractual obligations are not

[86] Potter and Enoch (1997)

being met. Another example for competitively tendered service contracts is linking of costs or fares to economic or performance indexes. By automatically adjusting fares periodically according to the country's price index for the duration of the concession, the contract can adapt to economic fluctuations.

Transparency in governance is key to reducing "regulatory capture,"[87] where the governing agency ends up serving the interests of the private actors rather than the consumers. This is minimized by opening up the bidding and regulatory process to public review and publishing the criteria and the results.

Contingency plans are needed to anticipate crises and ensure long-term sustainability. For example, all wining concessionaires must keep an excess amount of bus capacity on-hand, typically 5 to 10% of the total requirement for that particular time and day. This would minimize the impact of mechanical failures or accidents on overall service quality. For such a regulation to be successful, contract enforcement is paramount.

Traffic enforcement is also essential for sustainability. A system of violation points for either non-compliance or safety violations should be devised to allow the regulatory agency to periodically assess the performance of the operator. Licensing can also be used as a tool to ensure minimum environmental and safety standards and a constraint on the size of the sector. This would also require active on-street enforcement. Despite the existence of a large set of regulations for colectivos in Mexico City, understaffing, corruption, and unclear responsibilities have left regulations largely unenforced.[88] A prime example of the lack of enforcement in Mexico City are the right lanes of major arterials which are intended to be used by public transportation vehicles. However, it is common to see a vehicle parked or making an illegal right turn on this lane, thereby slowing transit services.

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[87] Based on interview with M. Jordan-Tank, July 2000.
[88] Cervero (1998), pp. 393

4.7.3 Optimizing Cost Effectiveness and Level of Service

By splitting public transport functions, it is possible to isolate political pressures, capture private entrepreneurship in operation, and the efficiency of coordinated planning. London is the best example of this hybrid regulatory framework where the city government retained the function of service planning but progressively tendered more and more routes to private operators. The former monopoly, London Bus, became just another bidder in the process and was encouraged to compete on cost with the private firms. This arrangement has numerous benefits; however, it also does create an informational gap between planners and operators that could be sub-optimal. One of the biggest complaints of operators in London is that they should have the power to redefine a route or schedule because they are on the street everyday. One approach to mitigate such a problem could be the development of databases and information technologies that are centralized but are accessible to all parties. This could also help bridge the on-street expertise of the operator with the systematic approach of the planner.

By holding the concessionaire accountable to public satisfaction, the quality of public transportation services can improve appreciably. A few systems in Latin American have begun conducting customer surveys of service quality, most notably in Buenos Aires. This information is then used to determine the compensation rate of a contracted service.

Where route associations do not currently exist, it may be beneficial for the regulatory agency to assist in developing formal associations that provide a minimal level of organizational structure. These associations would, in turn, recruit members to operate their own vehicles. The expectation is that these associations can eventually incorporate and be active participants in the bidding process of services. Although the Mexican government tends to view route associations as opponents or resistors to their authority, it may be in the best long-term interest of the public to encourage the appropriate development of these organizations on the periphery of the city where colectivos are not well organized. By building interdependence from the beginning, the regulatory agency may have more leverage in the long run.

4.7.4 Advancing Environmental and Mobility Objectives

Metropolitan governance should be aligned with regional objectives. Environmental issues such as air and water pollution do not conform to political bondaries. In principle, there should be one body governing region-wide issues and it should be superior to any of the member cities or municipalities it comprises. This is especially challenging when multiple levels of government exist, as in Mexico City, where federal, district and local jurisdictions overlap. An integrated regional government structure is one where goals are set by consensus, plans are continuously revised, and responsibilities are divided rationally. Curitiba, which benefited from strong and continuous leadership over decades, is one of the best examples of this concept although the periphery of the region has received much less attention than the city itself.

Coordinated governance can facilitate in planning for environmental and mobility objectives together. In Quito, for example, public concern over air quality propelled the formation of a true regional organization that planned and implemented a very successful electric trolleybus system. Another example is the regional government of Santiago de Chile, which has recently developed a contingency plan for public transport to be enacted on air quality emergency days where concentrations exceed certain limits. The "Plan de Prevención y Descontaminación" of the metropolitan area spells out a set of measures that temporarily restrict private vehicle use on key roadways while increasing the frequency of Metro and bus services. Simulation modeling estimated that the 19% expected shift of private vehicle trips to public transport could reduce emissions by 10% on average.[89]

Technological innovations have been and will likely continue to be important to air quality improvement strategies. In the United States, for instance, vehicle emissions control technologies, fuel reformulation, and fuel efficiency improvements have together accounted for virtually all of the mobile source emissions reductions.[90] Therefore, the

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[89] Based on a presentation given by CONAMA (the metropolitan government of Santiago) entitled "Red Vial de Emergencia para el Transporte Público: Impacto Ambientales" in Mexico City, March of 2001.
[90] Based on a presentation by Dr. Arnold Howitt, of the Harvard KSG, at MIT on 2 May 2001.

real opportunity for the developing world is to apply state-of-the-art technologies of the developed world rather than older and less effective technologies. By "leap-frogging" forward, developing countries can avoid the same developmental history or the mistakes. The challenge, of course, is that advanced technologies often come at a premium, at least in the short-term. In the long-term, however, advanced technology transfer can be beneficial to both supplying and receiving countries with proper financing from multilateral development banks or other institutions. The best example of this is the cellular phone, which has eliminated the need to install costly landlines in many developing countries. Another example of such advanced technologies are fare instruments, such as "smart cards", that could facilitate the administration of a bus system with multiple operators. It is also plausible that a public transport system with hundreds of individual private owner-operators could use a common card technology for remuneration.

Technological solutions should also match the decentralization of the problem they are trying to solve to the extent it is economically feasible. For example, the best possible inspection and maintenance program is to place diagnostic and monitoring devices on the vehicles themselves that can transmit data to remote sensors on the roads. This would provide, real-time and real-world emissions data. Although this plan may be cost prohibitive in the short-run, it may be a very worthwhile investment if it leads to better problem evaluation and decision-making.

4.8 Conclusion

Whereas most cities of the developed world have public transportation systems operated or strongly regulated by government entities and are moving toward greater private participation, Mexico City has a loosely regulated system with the vast majority of all road-based public transport vehicles owned and operated by private interests. For reasons described, private participation in road-based public transit in Mexico City is likely to continue. The management of private providers of public transportation is therefore essential.

Public Transportation regulations may be motivated by a number of different reasons, as was described in Section 4.2, including development, equity, politics, or environment. In the case of Mexico City, the greatest motivators are believed to be environmental (i.e. emissions reductions), economic development (i.e. mobility enhancement), and financial sustainability (i.e. operating costs and revenues from transit). The corridor model described in Chapter 3 was constructed to quantify the impacts of various measures according to these objectives. The following chapter addresses issues of integration of transit services and the potential to achieve both objectives in Mexico City.

Chapter 5. Integration of Transit Services

5.1 Introduction and Motivation

This chapter explores the integration of public transportation services and its potential to improve or maintain mobility while reducing transportation-related emissions. Three general approaches are suggested— modal, network, and institutional integration— and strategies are applied to the Mexico City case.

To understand the motivation for this chapter, one needs only to consider the likely future of transportation and mobility in Mexico City. In a recent Mexico City future scenario analysis, the number of passenger trips in the MCMA were projected using numerous assumptions about demographic, economic, and trip-making patterns over a 20-year horizon.[91] The results, shown in Figure 5-1, estimate a 76% increase in the number of trip segments in the MCMA from the year 2000 to 2020. Coupled with a marked shift towards private automobiles, as shown in Figure 5-2, the result could be a doubling of emissions from mobile sources. This would have a profoundly negative effect on air quality in the MCMA.

The challenge is to support the growing mobility needs of the region while reducing emissions from mobile sources. At the center of this question is the role of public transportation which is still expected to carry a majority of trips in the MCMA in the year 2020. Public transport will also have to share limited road space with an increasing number of private vehicles in the future. The low road space to land area ratio in Mexico City compared with other major cities will make capacity a serious issue. The lack of an adequate road network is particularly evident in the connections between the DF and EM where more than 6 million trips occur every day.[92] Cervero (1998) states that Mexico

[91] Refers to the scenario analysis presentation by the faculty and students of the MIT Integrated Program on Urban, Regional and Global Air Pollution on 9 March 2001 at El Colegio de México.
[92] Based on 1994 INEGI Origin-Destination Study

City's "congestion and [air] pollution problem would be much worse were it not for the dynamic and wide-ranging transportation system that has evolved over the years in response to explosive growth." In light of this, this chapter will address the need for public transportation modes to continually evolve to achieve higher efficiencies and effectiveness through integration and coordination.

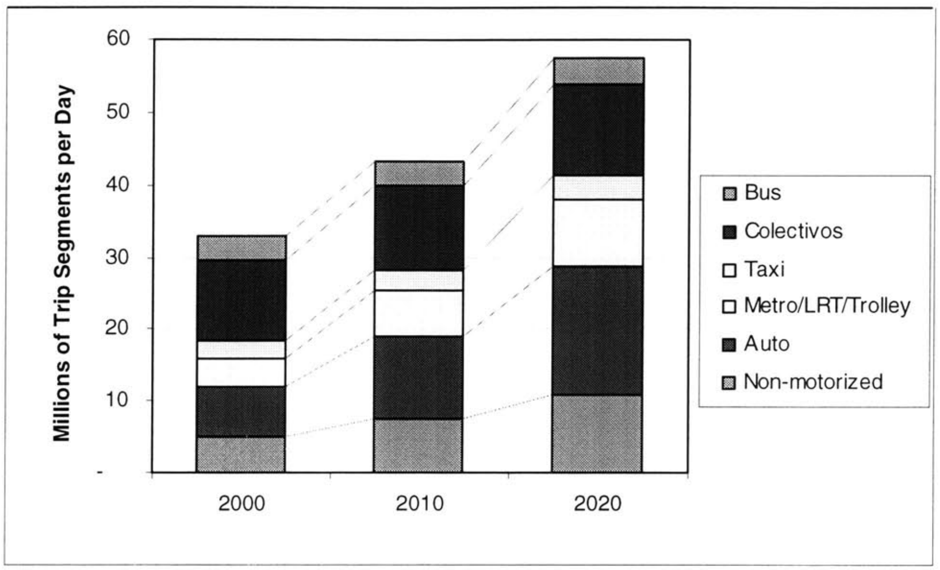

Figure 5-1: Reference Projection of Passenger Trips by Mode in the MCMA

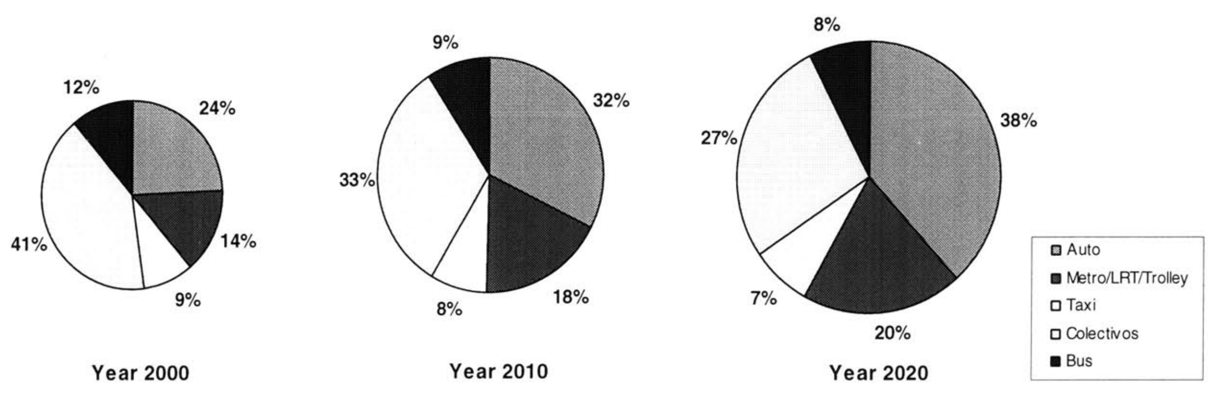

Figure 5-2: Projection of Mode Shares for Passenger Trips in the MCMA

5.1.1 Previous Research on Intermodal Integration

Intermodal integration is a complex topic that includes network design, service characteristics, transfers, fare integration, political realities and numerous other issues. Extensive literature is available on many of these individual topics but few papers address the integration of several modes in an environmentally-constrained and developing world context. This section highlights some of the most relevant research on the aspects of intermodal integration.

One of the foci of this thesis is the management of road-based public transport such as the conventional buses and colectivos of Mexico City. To date, several papers discuss strategies to improve informal transit or jitney services. Takyi (1990) describes the conditions under which jitney services can arise and be economically viable. He points to several cities with relatively inexpensive labor, inadequate conventional transit services operated by public or private entities, and low public expectations for service, comfort and safety as key ingredients for the success of informal transit. He also identifies potential roles that jitneys can fulfill in large transportation systems such as a supplemental capacity and parallel service during peak hours, service to new, low-density or relatively inaccessible areas with narrow streets. Takyi concludes that buses and jitneys provide different types of services in most cities and therefore complement rather than compete with each other. This is clearly not the case in Mexico City where colectivos have almost entirely consumed the public bus mode share in the last decade. Colectivos also compete with the Metro on some parallel routes. He also concludes that jitneys, as other modes of public transport such as the bus or metro, become less attractive to users and less financially viable as income per capita and automobile ownership rise.

Several other works have been written on the *públicos* of San Juan, Puerto Rico with respect to the new 17-kilometer heavy rail system currently under construction, called *Tren Urbano*. Lau (1997) identifies niche markets for jitneys and government policies from cities around the world. He develops a framework to evaluate potential intervention strategies to improve the públicos of San Juan. He concludes with a set of strategies for the poorly performing routes, those routes complementary to the Tren Urbano and public bus systems, and those routes in competition with the rail or bus service. These include using contracted services, government assistance with vehicle procurement and terminal stations, and fare integration. Figure 5-3 below is of numerous *carros públicos* in a government-funded terminal in the city of Ponce, Puerto Rico. The terminal was built to facilitate and optimize the flow of passengers and eliminate on-street storage of vehicles during the day. Públicos vary in size from large sedans to the 15-passenger vans shown in Figure 5-3.

Figure 5-3: Público Terminal in Ponce, Puerto Rico

The principal dissimilarity between the público and colectivo systems is that privately-operated jitney services in Mexico City are generally profitable while públicos are steadily losing market share in Puerto Rico to other modes (primarily the private automobile). Emblematic of the dying business are the aging público vehicles and operators. On the other hand, colectivos in Mexico City hold a majority of the public transportation market in Mexico City and continue to be a viable business despite aging vehicles.

In his thesis, Lin (2000) investigates strategic bus service planning in the context of a phased introduction of a new rail system, specifically the introduction of Tren Urbano into the Santurce/Old San Juan corridor. He contends that integration issues related to capacity, coordination, and the overall success of a bus-rail interface can be addressed effectively with the strategic planning of bus service. Lin identifies an operating environment assessment process that includes three planning horizons (short, medium, and long-term), three levels of activity systems (local activity, urban infrastructure, and public transportation system), and three perspectives (customer, operator, and community). Moreover, he identifies the minimization of time costs from transfers between modes and routes as vital to the success of an integration plan.

Denant-Boèmont and Mills (1999) examine intermodal integration in various North American cities from an economic standpoint. They conclude that intermodal competition is preferred over coordination for reasons of costs. Their thesis is that on-street competition may be beneficial to passengers although the level of service and financial conditions of some modes may suffer as a result. This conclusion, however, is limited by the political and social realities of public transport in the developing world. The preponderance of evidence suggests that more coordination and integration is beneficial in loosely regulated environments such as public transportation in Mexico City. One of the chief arguments against competition in urban transportation is the existence of economies of scale to some extent for larger firms. This argument is dependent on the degree to which public transportation functions as "natural monopoly".[93] This theory, however, is highly debatable and in any case beyond the scope of this thesis.

Lee (2000) investigates the integration of the new rail system with existing bus transit services in San Juan. In his thesis, Lee addresses various aspects of intermodal integration including network design, fare policy, and institutional issues. He also develops a planning framework for bus-rail integration and applies it to the San Juan bus

[93] Gómez-Ibáñez et al. (1999)

and público systems. Specifically, he identifies objectives, criteria, and approaches to integration which are described in the following sections.

5.1.2 Integration Objectives

A preliminary step in intermodal integration of transit services is to establish key objectives. This involves considering the strengths and weaknesses of the existing system, socio-demographic trends and travel patterns, as well as the political and financial realities.[94] These objectives typically include:

- Increasing ridership by attracting new transit riders or shifting users of less-preferred to preferred modes
- Retain the existing ridership on the preferred modes
- Maximize the efficiency of the existing system
- Improve financial productivity

In the case of Mexico City, there is a dual objective: (1) maximize the efficiency of the public transport system and (2) reduce the negative externalities from vehicular emissions. In light of this, it is the stated policy of the Mexico City government to promote and expand high-capacity modes, namely the Metro and light rail system. This proposed expansion must be done in the context of intermodal integration with the other low and medium-capacity modes.

5.1.3 Integration Criteria

Once broad objectives are established, it is necessary to develop criteria to evaluate individual integration plans. Of course, these measures are highly dependent on the location, conditions, and the organization applying them. However, the following is a set of general criteria that may be used:

- **Network coverage and connectivity** affect the ability of public transport users to travel from origin to destination. Network coverage implies the accessibility of a

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[94] Lee (2000)

system to a region while connectivity refers to the interface between modes to complete trips.

- **Service frequency and span** are major factors influencing the mode choice of potential system users because they affect the wait time and the ability to reach certain off-hour activities.
- **Service reliability** is measure of the consistency of on-time arrivals and departures and is another key factor in passenger mode choice.
- **Ridership or passenger volumes** can be affected by any substantive service change and must be measured as both the impact on existing and new riders.
- **Equity** is an ever-present issue with any changes in transit service since it is likely to create new costs and new benefits for stakeholders. It is unrealistic to plan a system where all people receive the same level of service but it is particularly important to estimate the impact of changes on people of different income levels and mobility needs.
- **Costs and revenues** to the operating entity may be affected from changes in service or fares. As seen in the corridor model (Chapter 3), profits can vary non-linearly with system changes because they can affect ridership, the size of the fleet, and labor costs simultaneously.
- **Service effectiveness** is a measure of how a service is utilized in terms of passengers per vehicle kilometer or vehicle hour. Changes in ridership levels, network coverage, service frequency, or service span will all have a direct impact on this measure.
- **Cost efficiency** is a measure of the unit cost of providing a service, independent of ridership (e.g. labor cost per vehicle kilometer of vehicle mile)
- **Cost effectiveness** is a wide-encompassing measure relating costs, revenues, ridership, service effectiveness, and cost efficiency. The net profit (or subsidy) per passenger is a common measure of cost effectiveness.
- **Political acceptability** is a key factor in implementing any integration plan. It may not be sensible to pursue a strategy that optimizes a service, productivity, or performance criteria if it is not politically acceptable.

5.1.4 Integration Approaches

- **Incremental Approach**

The incremental approach makes modest changes towards greater system integration. Also known as a minimalist approach, minor and obvious changes are made first to avoid negative impacts to the current stakeholders. The advantages of this tactic are that a coalition of support can be built over time to implement the necessary changes and there is enough time to fully refine integration plans. However, this typically requires political continuity, which does not exist in many cities where political parties of differing ideologies fiercely contest local elections. Moreover, this approach may miss opportunities and lead to inefficient use of resources over time.

- **Priority Approach**

The priority approach allows for the emphasis of one mode or system, such as the Metro in Mexico City. As a result, other modes may be eliminated, reduced, or relegated to a feeder or supporting role. Political will and wide public support is required to set priorities. This method tends to be problem-centered rather than systematic because one mode is unlikely to serve all possible needs. Again, this may not be the most efficient use of resources in the long run.

- **Integrated System Approach**

The integrated approach attempts to create a system that takes full advantage of the strength and weaknesses of various modes by objectively considering their financial and operational effectiveness and efficiency.[95] The result of such an analysis is a comprehensive plan that may face political challenges. This method may include elements of the incremental and priority approaches to improve its acceptance. Overall, this approach is preferable in the long-run and will be the focus of this work henceforth.

The integrality of vehicles, infrastructure, control systems and decision-making is fundamental to transportation systems design.[96] The following sections will describe three dimensions to the integration of transit services and their relevance to Mexico City.

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[95] Lee (2000)

[96] Sussman (2000)

(1) The integration of transit modes involves achieving an optimal balance between available technologies and their impacts;
(2) A geographic dimension considers network integration at various levels from system, to corridor, to station or stop; and
(3) The integration of institutions and coordinated governance facilitates the generation and implementation of a plan.

5.2 Modal Integration

Transit services in large cities are made up of many modes. Public transportation is typically a component of a larger transportation system. This greater system can be characterized as a CLIOS, "a complex, large-scale, integrated, open system" [97], where the interrelation of sub-systems and components makes predicting changes very difficult and unintended consequences are commonplace. As a case in point, in the 1970s the World Bank led efforts to privatize and "atomize" public transportation services in many cities of the developing world without considering the integration of modes. The benefits sought from the promotion of informal and privately-operated transit were the low investment costs, short implementation time, and market efficiencies driven by competition. However, after the markets were established, numerous negative externalities became apparent, such as congestion, safety concerns, illegal activities, and pollution. It became very difficult to change the system thereby forcing governments to revert to an incremental approach. Critics later viewed the World Bank strategy as a "Trojan Horse" because the unintended consequences were often not fully realized until much later.[98] There is still considerable disagreement over the appropriate role and impact of private transportation services, whether clandestine or authorized, informal or organized. This section will discuss the questions of whether informal or intermediate transit is a beneficial mobility service for people who may not otherwise have it, whether is it also a positive alternative to the private automobile, or whether is it leading to the demise of the conventional public transportation systems as some fear.

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[97] Sussman (2000)
[98] Brasileiro et al. (1999)

5.2.1 Characterization of Modes and Transit Services

The diversity of public transportation modes in Mexico City is presented in Table 5-1.

Table 5-1: The Public Transport System in Mexico City

Mode	Operator(s)	Principal Characteristics
Heavy Rail (Metro)	STC (Sistema de Transporte Colectivo) - a decentralized public agency	High capacity mode in an exclusive right-of-way
Light Rail (Tren Ligero)	STE (Servicio de Transportes Eléctricos) - a decentralized public agency	High capacity mode in an exclusive right-of-way
Trolleybuses (Trolebuses)	STE (Servicio de Transportes Eléctricos) - a decentralized public agency	Medium capacity mode operating in mixed traffic with fixed routes and stops
Buses (Autobuses)	• Articulated buses operated by the STE • The "Consejo de Incautación" operates part of the routes from the defunct Ruta-100 • Several private bus companies	Medium capacity mode operating in mixed traffic with fixed routes and stops
Microbuses and Vagonetas	Colectivo route associations which integrate individual concession-holders with not more than five vehicles.	Low capacity mode operating without a schedule in mixed traffic with mostly fixed routes and stops on principal corridors
Roaming and Station Taxis (Taxis libres y de sitio)	Individual operators, some belonging to association (primarily the station taxis)	Individual service without fixed routes
Bicycle Taxis (Bicitaxis)	Individual Operators	Short-distance individual service without fixed routes

Source: SETRAVI (1999) chap. 3, pp. 21

Heavy rail systems, sometimes known as a metro or subway, run on exclusive and fixed guideways underground, at surface, or elevated. Some systems may operate like heavy rail but not utilize the conventional steel wheels. For example, nine of the ten Metro lines in Mexico City operate rubber-tire trains. This French technology allows for faster acceleration and deceleration, and shorter station spacing, but requires greater maintenance. These systems are typically electrically powered.

Similarly, light rail systems are typically steel-wheeled trains but somewhat smaller in size and have greater maneuverability. They may also be known as trolleys and typically receive electric power from overhead wires. Mexico City has a single, recently-built light rail line. The rubber-tire public transportation vehicles include buses, microbuses, vans, sedans, and taxis. Most of these vehicles are powered by independent internal combustion engines although there are electric trolleybuses and non-motorized taxis.

The operations of any transit mode can vary on two fundamental dimensions, geographic and temporal, as shown in Figure 5-4. The geographic dimension is related to the route variance from entirely variable, such as a taxi, to entirely fixed, such as a rail line. Temporal variance is associated with the scheduling of transit services and, again, a taxi service has a more variable schedule of operation than rail services. The physical limitations of rail systems (i.e., fixed guideway, costly and time-consuming construction, larger vehicles) make it less operationally flexible than conventional rubber-tire modes. However, rail systems are typically the most cost efficient method of moving large masses of people once the required infrastructure is in place. In general, the consolidation of like-demands reduces the operating costs of a transit system.[99]

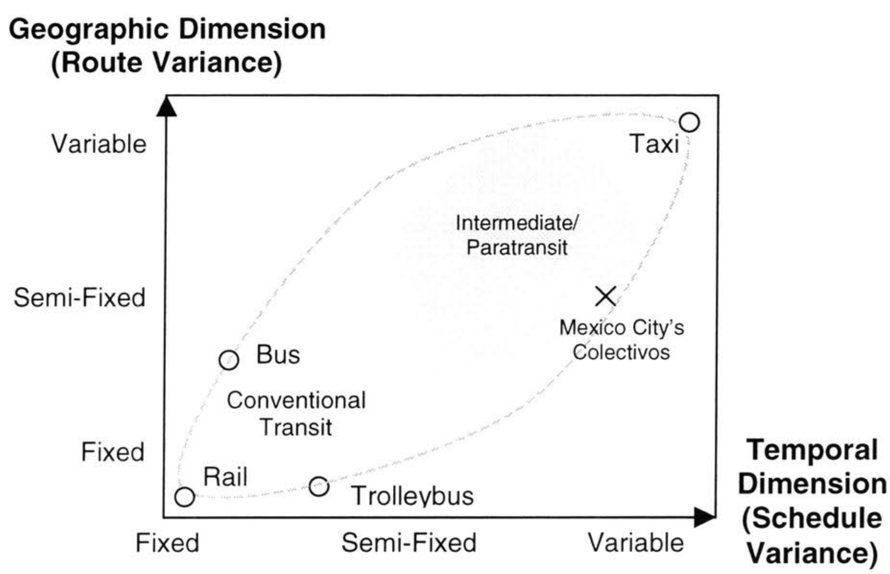

Figure 5-4: Comparison of Transportation Service Operations[100]

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[99] Sussman (2000)

[100] Adapted from a presentation given by Prof. T. R. Lakshmanan, Boston University, Center for

Buses, microbuses, vans, and taxis have far greater operational flexibility than the Metro. Mexico City's colectivos, composed primarily of microbuses and vans, operate essentially as intermediate transit or paratransit service with a highly variable schedule and informal organization. The route structure is "semi-fixed" with hundreds of variants and branch routes served and periodically changed. The operators also stop at any point along a route to pick up or drop off passengers. It also retains certain aspects of a demand-responsive service since the owner-operator determines the hours and days of operation based on passenger demand. They are, however, are loosely self-regulated by route associations. Operators also often wait at terminals until their vehicles are at least half-filled to capacity or until a maximum wait time has passed. If the operator feels that more passengers will be waiting along the route, they may also wait until a certain number of passengers have boarded. The driving motive behind these policies is to maximize profits by increasing revenues or decreasing costs. One of the sources of costs to these operators is roadway congestion, which increases fuel expenses and the opportunity cost from the lost turnover of seats.

The operational characteristics of modes also affect their capacity and costs. Investments in infrastructure and capacity are often "lumpy" or discrete.[101] A rail or metro system exemplifies such an investment. Lines and stations have been incrementally added to the Metro system in Mexico City over the course of three decades. Opening a new line substantial increases capacity, and often, but not necessarily, passenger ridership as well. Compared to the Metro, of course, a bus network in Mexico City is more flexible because it does not necessarily require new infrastructure. Nonetheless, the capital costs of vehicles themselves can be quite expensive.

Compared to the publicly-operated buses in Mexico City, namely the RTP, colectivos are more flexible still. Microbuses and vans are continuously being added and removed from the surface transportation system. The vehicles providing colectivo-type services have a

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Transportation Studies, in April 2001.
[101] Sussman (2000)

much smaller passenger capacity and are much less expensive than buses. In this manner, the colectivo mode is able to supply services according to the perceived market demand and other external factors. By more closely responding to market forces, the mode has an inherent advantage over longer-term and more capital-intensive modes. Its responsiveness and agility also allows it to respond to short-term stochastic changes in demand. Its main constraint lies in the availability of infrastructure (i.e., roads and highways) that can take a long time to be improved or expanded.

The "lumpiness" phenomenon is also evident in the time frames involved in the planning and implementation of changes to different system components. Transportation system components and relevant external systems operate and change at different time scales.[102] It often takes more than a decade from the inception to the operation of a new metro line. Several of the current ten lines will be extended into the EM, and new lines will be built, with the aim of approximately doubling the track length by 2020. In contrast, while bus and colectivo routes are subject to a certain level of regulation, they can be changed much more quickly. In theory, a change in a route that does not involve infrastructure could be implemented in a day.

5.2.2 Intermediate and Informal Modes

When the mobility needs of a segment of society is not being served by the established public transport system, alternative transit services may emerge in an open market and/or be warranted. These services are known as informal transportation, jitney services, or in a broader sense *paratransit.* Paratransit is a term coined in the 1970s to describe the full spectrum of transportation options between the taxis and the conventional bus. In describing commercial paratransit services in the United States, Cervero (1996) describes it as a niche market industry in the sense that it "fills in the gaps and expands the service options of urban transportation along the continuum between private automobile travel on one end and conventional fixed-route transit on the other." Table 5-2 presents the wide

[102] Sussman (2000)

spectrum of privately-operated transportation services with some basic characteristics and examples. The shaded area represents the breadth of paratransit services.

Table 5-2: Spectrum of Privately-Operated Transportation Services

Type of Transportation	Routes/Stops	Origins to Destinations	Demand Response	Capacity	Markets	Prime Examples
Private Automobile	On-demand	One-to-one	On-call	1-4	Private	--
Exclusive-ride Taxi	On-demand	One-to-one	Curbside/hail or phone	1-4	General public	--
Shared-ride Taxi	On-demand	Many-to-many	Phone or curbside	3-4	CBD, Airports, Train Stations	Many cities of the developing world
Dial-a-ride						
Specialized	On-demand	Many-to-many	Phone or reservation	4-10	Elderly, Disabled	Numerous large North American cities
Airport Shuttles	On-demand	One-to-many	Curbside or phone	4-10	Air travelers	Super Shuttle, numerous U.S. cities
Employer or Developer-Sponsored						
Shuttles	Regular	Few-to-one	Pre-arranged	6-15	Commuters, Students	Numerous large North American cities
Van or Buspools	Regular	Few-to-one	Pre-arranged or scheduled	6-60	Commuters	Numerous large North American cities
Jitneys/Informal Transit						
Circulators/ Corridors	Regular or Semi-Regular	Many-to-many, loops	Curbside or fixed stops	12-40	Commuters, public	Mexico City's colectivos, San Juan's públicos
Transit Feeders	Regular or Semi-Regular	Many-to-one	Curbside/hail	12-20	Transit users, public	Mexico City's colectivos, San Juan's públicos
Area-wide	Semi-regular	Many-to-many	Curbside/hail	12-40	General public	New York, Miami jitneys
Conventional Bus Transit	Regular	Many-to-many	Fixed stops, scheduled	40-80	General public	--

Sources: Cervero (1996) and Wright (1992)

As seen above, paratransit refers to a broad range of services that do not necessarily have fixed routes or guideways. It operates in the wide gap between large transit vehicles (buses and rail transit) and automobiles. The remained of this thesis focuses mostly on one particular segment of the spectrum— jitney and informal transit services, which are the most common form of paratransit in the developing world. Some of the other distinguishing characteristics of the service beyond passenger capacity, type of clientele or market, and the service type listed in Table 5-2 include:

- Level of regulatory control by government, including municipal, state, and national, or other entity;
- Type and level of sponsorship or subsidy (i.e., pure entrepreneurial services or funded by government, employers, or developers);
- Level of individualism or cooperation between vehicles or operators (i.e., the balance between level of competition and coordination);
- Type of owner-driver relationship (i.e. organizational structure and compensation)

The success and persistence of informal public transportation services in many Latin American cities alarm many government and public transportation officials due to the competition with metro and bus services. Kaysi et al. (1999) investigate the role of that the private or informal transport sector, such as jitneys, may play in the larger public transportation system. They contend that the private sector can supplement or complement instead of compete with conventional transit services. Their work identifies the challenges facing private sector modes and potential external intervention strategies to improve their operations. These include regulation, financial assistance for capital expenditures, and contracted operations. Their paper applies these strategies to improve the públicos of San Juan.

5.2.3 Potential Advantages of Informal Transit

To understand how jitney services or informal transit can thrive, one need only visit a megalopolis like Mexico City. Flexible and agile owner-operators are able to capitalize on the lack of public transportation service and create a market of their own. This is combined with the inherent flexibility and adaptability of small-vehicle transportation to make colectivos a viable option in both distant neighborhoods and dense downtown areas. To provide further insight on why jitneys have proliferated in certain places like

Mexico City, the following are possible advantages of jitney services over conventional public transportation modes or even the private automobile.

- Lower total trip cost resulting from more frequent service and/or faster travel time

In general, smaller vehicles have the advantage of taking less time to load and unload, are more maneuverable in traffic, and can accelerate and decelerate faster. These factors can translate into a faster travel time and a lower cycle time. They can also increase the service frequency (lower headway) and reduce the wait time of passengers at stops. In Mexico City, the combination a faster travel speed and lower wait time offset the fare premium of colcetivo service over the government-operated bus system

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- More direct service and greater accessibility to vehicles

Jitney vehicles typically stop at request along a particular route thereby dropping off passengers closer to their destinations and picking them up closer to their origin. They also typically have a larger route structure and coverage. In Mexico City, colectivo serve over 100 routes and hundreds of additional branches from these major corridors.

- Potentially more cost efficient per passenger than other road-based transit modes

A high degree of market responsiveness means that vehicle occupancies and revenues can be high relative to operating costs. A high profit margin eliminates the need for a government subsidy and attracts more operators to the service. Jitneys are inherently fragmented and hence highly competitive. Where there is little or no government regulation, the competitiveness usually results in the emergence of informal self-regulation through route or operator associations. Due to the flexibility and diversity of jitney services, they are more likely to capture the market's willingness to pay and many times command a higher fare.

- Enhance overall mobility and economic activity

Perhaps the key benefit of paratransit services is that it can improve the overall mobility of the residents of a city or region. Mobility is a key ingredient in the growth of economic activity. Conversely, a lack of mobility can also stifle economic growth.

- Provides employment and business development

A primary benefit of an accessible informal transportation sector with minimal entry barriers is that it provides almost immediate employment. This is especially relevant in the countries of Latin America where unemployment rates can reach 20% of the able population. Compared with conventional transit, informal modes require more drivers due to smaller vehicles. Nevertheless, these drivers rarely receive the compensation and benefits of drivers in more formal organizations. In a well-regulated and sustainable environment, a professional culture can develop around jitney services and successful small business can expand. This also has positive repercussions in other areas of the economy.

Additionally, Cervero (1996) identifies the following as primary and secondary benefits of well-regulated commercial paratransit services. These are most appropriate for the developed world where public transportation is typically government-controlled or operated.

- Impose market discipline on the established public transportation system

Jitney services are often more cost efficient than conventional public transportation. The cost savings come primarily from lower-priced labor and higher productivity of vehicles in the form of higher passenger loads and seat turnover rate. The increased competition may push public transit agencies to concentrate mainly on serving high-density, high-volume corridors which enjoy the greatest economies of scale. Paratransit can be an economic asset by eliminating the need for government subsidies and relieving public transit agencies of costly peak-hour burdens.

- Increase in the diversity of travel choices and quality of service

A potential benefit of paratransit may be an increase in the mix and overall quality of transportation options. This may include greater ride comfort, a guaranteed seat, or amenities. Many commuters in the developed world choose transit over other modes due to an unwillingness to deal with traffic congestion during peak periods or because it provides productive time for reading or working. By serving a higher quality and price market, paratransit may be able to attract and retain "choice" riders, or those who may have a private alternative for their trip making.

A prime example of this exists in the city of Porto Alegre, Brazil. Porto Alegre saw a complementary service known as "lotação" emerge in 1977 when taxi owners began to acquire higher-capacity vehicles (i.e., kombis) and operate them on fixed routes. Currently there are 40 lines with 403 minibuses seating 17 to 21 passengers. These luxury vehicles (shown in Figure 5-5) are equipped with air conditioning and cellular telephones, and demand a fare that is about 20% higher than the regular public bus service. A recent on-board survey estimated that the service transports 70,000 passengers per day, 44% of which were choice riders who own automobiles.[103]

Figure 5-5: "Lotação" Service in Porto Alegre, Brazil
(Photograph by José Alex Sant'Anna)

- Improve accessibility of transportation services to disabled and elderly

Paratransit is a common provider of socially-desirable and specialized services to the disabled and elderly in many North American cities. It is easier to equip vans or microbuses with special equipment than large buses. This avoids having to make every

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[103] Sant'Anna (2000)

feature of a public transportation system accessible with costly systems, such as elevators. Smaller vehicles may also be more comfortable or safer for the user.

- Stimulate innovations in advanced transportation technologies and Intelligent Transportation Systems (ITS)[104]

With a well-regulated and effective paratransit sector, it is likely easier to introduce advanced public transportation technologies. For example, alternative fuel technologies such as natural gas and electric lend themselves to smaller vehicles more readily than conventional buses. Communication technology is also more useful at making flexible services, such as paratransit, more efficient than larger vehicles with fixed routes. A healthy paratransit sector could also create a real market for the consumption and continued development of advanced transit technologies. One can envision fleets of "smart vans", not only more efficient but more accessible to riders with disabilities.

- Improve service to poor and rural areas

Public transportation has always faced equity issues especially as it provides a majority of mobility services to the poor areas of many countries. In the United States, paratransit has been identified as a tool to mitigate the "spatial mismatch" that exists where the poor live closer to downtown areas where the high-skill jobs are located, and far from lower-skill jobs in the booming suburbs. Similarly, paratransit can be a benefit to those in rural areas too distant to access the mainline transit systems.

In the developing world, intermediate transportation services also have the ability to serve low-density settlements in the periphery of the urban area. In Mexico City, vast areas of irregular or illegal settlements exist on the fringes of the MCMA, particularly in the EM. Colectivos are often the only available mode of public transportation for the people living in these irregular settlements because it can negotiate the poor and unpaved roads.

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[104] Cervero (1996)

5.2.4 Potential Drawbacks of Informal Transit

Despite these advantages, informal transport has a poor image and reputation. Its profits are often based on low salaries and the exploitation of the operating crew. It has an association with poverty and disorder viewed unfavorably by governments trying to reduce its role. The World Bank identifies three main aspects of informal transport systems which contribute to this image, (1) dangerous on the road behavior, (2) an association with the poor, crime, or violence, and (3) the undermining of the basic transit network.[105] The following paragraphs address these issues and others.

- Operating Behavior and Practices

A high degree of market responsiveness may lead to cutthroat competition on the road and an oversupply of services in the most profitable areas and hours of the day and a undersupply in other areas and hours. Competitive pressures on owners and drivers trying to earn a living sometimes result in excess capacity, low load factors, and consequently aggressive driving and dangerous operating practices such as racing, short-turning, and blocking. The general lack of attention to passenger and road safety is a major concern for the government. There is ample anecdotal and factual evidence of such behavior in Mexico City. Crashes involving microbuses are well-publicized in major Mexican newspapers.[106]

The informal transport sector supplies a significant amount of urban employment in many developing countries. In many Asian cities, around 15% of the urban population are directly or indirectly dependent on informal transport for their livelihood.[107] However, hired drivers are not typically well paid, have low levels of education or training, and are often unlicensed rural-urban migrants or adolescents. These factors also have an impact on the operations and safety of these vehicles.

- Self-Regulation

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[105] World Bank, Urban Transport Strategy (2000)
[106] *La Reforma* newspaper. "Viajan Capitalinos en Microbuses Caducos." 28 March 2001.
[107] World Bank, Urban Transport Strategy (2000)

Proponents of free markets frequently argue that operators realize that it is not in their own long-term interests to continue the aforementioned practices. Typically, this results in the formation of associations by route or region which limit entry and organize more disciplined service. Such associations are the norm wherever the informal sector is unregulated. The World Bank (2000), however, identifies several problems with such self-regulation. Principally, it assumes that associations are outside direct public control and therefore tend to act only in the interests of its members. Since jitney riders tend to be captive in the developing world, this is generally true. Any measure of control customers could exert on transit services is limited by the lack of mobility alternatives. For instance, during the initial period of deregulation in Santiago, Chile, operator cartels rapidly increased fares as government restrictions were lifted. This did not have the expected negative impact on ridership because the users were mostly captive.

- Crime

Where there is a lack of formal regulations, informal self-regulation through operator associations often occurs. Because self-regulation is not typically based on any legal framework, associations often exert cartel power or resort to violence to protect their interests. These troubles are frequently exploited by vested interests such as corrupt police or other public officials who exploit the quasi-legal nature of the sector to supplement their incomes. Conventional operators may also exploit the limitations of the informal sector as reason for protecting the formal sector. The general atmosphere of crime and violence further repels higher-income passengers from the service. This reinforces its association with the poor.

- Sub-Optimal Operations

The need to ensure fair allocation of revenues between members often results in sub-optimal practices. For instance, controlling the dispatch of vehicles from the terminal to ensure a certain load does equalize revenues per vehicle but at the expense of passenger wait time and access time walking to distant terminals. The more secure and longstanding associations are able adopt more efficient practices. However, these efficiencies typically come at the expense of a larger degree of monopoly power. For example, the colectivo association operating on one of the largest and most traveled corridors in Mexico City, Route 2, hires dozens of dispatchers to control the flow vehicles and ensure that no "pirate" vehicle invades the market.[108]

- Encouraging Inappropriate Development

It has been observed that in Mexico City and other Latin American cities that poorly-regulated jitney services are the first to provide mobility services to newly-developed, distant, and sometimes illegal settlements. This behavior is reinforced by the intensification of development and population growth in these settlements. In turn, the growth increases the demand for public transport and the informal transit sector responds with more vehicles and increased service. The result is the unplanned development of areas on the periphery of the region where other public services and utilities are not readily available. This is believed to be an inefficient development pattern that encourages urban sprawl and government expenses.[109]

- Congestion and Environmental Impacts

The pressure of competition may also lead to an excess supply of vehicles or service and the use of small and often cheap older vehicles. Some argue that this is the case in Mexico City where colectivos compose up to 15% of the vehicular traffic on some corridors; the average vehicle age is about 8 years.[110] Small transit vehicles are usually much simpler and lighter in construction than conventional buses. In Mexico, colectivos were manufactured from converted chassis on a standard 3.5-ton gasoline truck platform. As a consequence, capital and operating costs increase directly with vehicle size (as shown in Chapter 3). Furthermore, if labor costs are also low, there is less incentive to use large vehicles which are more difficult for the informal sector to finance. As the effects of congestion and environmental impact are external to the individual operator, the primary incentive is thus to operate cheaply. Hence, old vehicles are often used. The

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[108] Cervero (1998)

[109] Presentation by Martha Schteingart, Professor of Urban Planning at El Colegio de Mexico, January 2000.

[110] COMETRAVI (1999) v.1

use of small, old, or ill-adapted vehicles has adverse impacts on urban congestion and air pollution. Totally unregulated entry in low income countries is likely to result in a higher level of congestion and environmental impact than is socially desirable.

However, some automobile owners and passengers, including in Mexico City, hold the belief (perhaps misguided) that colectivos and buses disproportionately congest the roadways and pollute the air. The storage of vehicles on the street during off-peak hours is another a common complaint. In reality, the reverse is true as public transportation vehicles contribute significantly less to urban congestion and pollution than private vehicle users on a per passenger basis. The key, therefore, is to consider passenger kilometers traveled (PKT), as well as the vehicle kilometers traveled (VKT) and the emissions factor (in grams per kilometer), in the estimation of emissions from mobile sources. Section 2.4 of this thesis provides a quantitative comparison of emissions by mode in Mexico City.

- Undermining of Formal Transit Services

Informal transit is sometimes accused of undermining formal network of transit services by attracting passengers from the established transit modes. This notion, however, may be misguided since passengers with travel alternatives will often choose the option with the least cost or most utility regardless of formal or informal organization. In Mexico City, there is significant competition between the publicly-operated bus and the colectivo because they are substitutable alternatives on many corridors. The interaction with the Metro, however, may be more complementary as 60% of all colectivo routes feed a Metro station.[111] Cervero (1998) views the extensive system of colectivo routes as effectively extending the draw and distribution of trips from the Metro network of stations. However, there are numerous parallel routes with buses and even the Metro. It is fair to assume that private, for-profit paratransit operators will only provide services where and when they believe is profitable to do so. This is a concern where socially-desirable yet unprofitable services exist. The provision of unprofitable services by cross-subsidization from higher-profit routes is perhaps the strongest argument for a monopolist public supplier. Nonetheless, London and other European cities have demonstrated that directly subsidized services can be efficiently obtained through competitive tendering of franchises.[112] The World Bank (2000) also points to experiences over many years in Buenos Aires and other cities of the developing world that competition can be organized in ways which both ensures disciplined service and allows the informal sector to be involved.

The World Bank (2000) points to a subtler problem emerging in many Latin American cities, such as Buenos Aires, São Paulo, and Fortaleza, and some East Asian cities, such as Bangkok, where informal operators are beginning to operate services in direct competition with traditional large vehicle services (whether operated by public or private enterprises). The advantage of the informal operator is that by operating smaller vehicles and a denser network of services, they are able to offer faster and more convenient service than the traditional operator. In some Brazilian cities, this is done at fares equal to or slight above that of the traditional operator. The World Bank (2000) states that the effect may be to reduce the demand for the established transport system, hence increasing the breakeven fare or lowering their breakeven frequency and lowering demand further in a vicious cycle. Once again, riders may be minimizing their total travel costs by choosing informal transit over the conventional modes.

The World Bank (2000) also states that probably the most serious impact of informality is on the development of integrated multimodal service and fare structures. In a number of Brazilian cities with a metro or suburban rail, the bus networks have been restructured to allow for fare integration. However, passengers are being lost to informal operators continuing to provide more direct service at competitive fares. The critical question is then— what, if anything, public authorities should do about this market-oriented response.

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[111] SETRAVI (1999)
[112] For more information on London's competitive tendering, the reader is directed to Section 4.3.4

5.2.5 Cost/Benefit Trade-offs

The identification of advantages and disadvantages reveal a fundamental trade-off between cost and level of service (LOS) of public transportation. Indeed, the trade-off between cost and LOS is a fundamental source of tension for any transportation provider and customer.[113] This equilibrium can also be characterized as a cost efficiency versus service effectiveness or the utility of mobility services versus their environmental costs tradeoffs. The costs and the benefits of service depend on the perspective of the analysis—that is, from the customer, producer, or some other stakeholder. A graphical framework of the trade-off is presented in Figure 5-6. The relative level of service is plotted against the costs and externalities. This framework is analogous to the one presented in Chapter 3 for mobility and emissions tradeoffs.

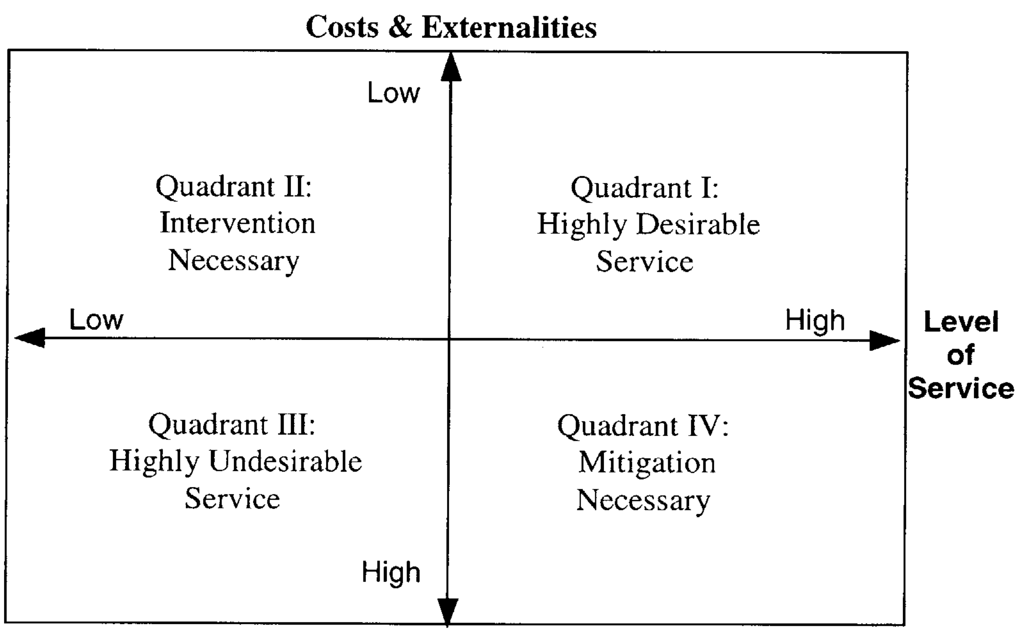

Figure 5-6: Cost Efficiency/Service Effectiveness Trade-off

Quadrant I is the happy but unfortunately unlikely confluence of a high quality and low cost transportation service or system. Perhaps the best example is a pedestrian in a congested downtown area. It improves the mobility and accessibility of destinations in a compact area while generating few if any negative externalities.

The Metro is a prime example of a Quadrant IV condition. By nearly all accounts, it provides a high LOS at a low price for Mexico City users but at a high cost to the provider. This necessitates high government subsidies. During the economic crisis of the mid-1990s in Mexico, costs of transit operation soared. The Metro (as well as most other forms of publicly-operated transit within the DF) currently charges a fare of $1.50 pesos, but its cost of operation has climbed from $1.94 to $4.26 pesos (expressed in 1997 pesos), mainly because of the economic crisis.[114] Public and political pressure to maintain low Metro fares, however, is substantial.

Informal transit or jitney modes usually lie in Quadrant IV offering public transportation services at a premium fare. In the spectrum of transportation alternatives from the private automobile to higher-capacity buses and metro, informal transit provides an intermediate option in terms of cost and level of service. The colectivos of Mexico City lie squarely in Quadrant II from the user's perspective due to their higher fare cost and high level of service (in the form of frequency and coverage). Society, however, also pays additional external costs described in the previous section. Despite colectivo fares being considerably higher on average than the bus or metro, the utility to the user is still greater in most cases as evident from its high mode share. Therefore, the colectivo mode is able to exploit its middle position to capture a large segment of the market without subsidy.

Quadrant III delineates the combination of high costs and low LOS and therefore is undesirable. Quadrant II is the convergence of both low costs and a low utility service. An example of this in many cities of the developed world is a clean and cost efficient network of buses that is too sparse or too infrequent to serve the mobility needs of potential users. A few jitney services from the developing world may also fall into this category by offering a lower fare than conventional transit that compensates for the lower LOS.

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[113] Sussman (2000)
[114] SETRAVI (1999)

5.3 Network Integration

5.3.1 Network Structure

The route network is one of the primary factors in the service effectiveness of a transit system. The networks are a function of roadway network geometry, the location and relative strengths of activity centers including the CBD, employment and residential densities, political and geographic boundaries, historic paths, and other variables. The following is a non-exhaustive list of basic network concepts which are also illustrated in Figure 5-7.

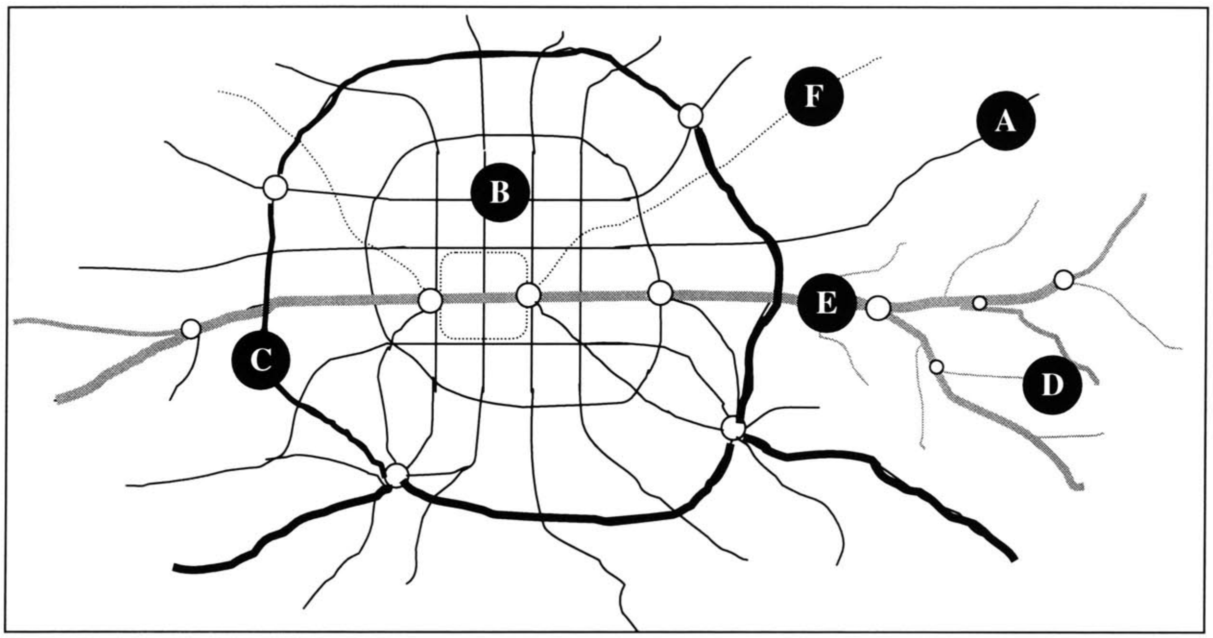

Figure 5-7: Transit Network Concepts

A. Radial

Many older cities exhibit a radial network between the central business district (CBD) and the surrounding suburbs and neighborhoods. It works best when a strong urban core is connected to peripheral activity centers. Under these conditions, a radial transit route can provides optimal service and travel times with direct service. A strong CBD and a compact urban footprint are very conducive to fostering the symbiotic relationship between frequent services and high ridership.[115] The primary drawback is a difficult suburban-to-suburban trip because it may involve an indirect route through the CBD.

B. Grid

A dense network of parallel and perpendicular routes is known as a grid. It typically can serve a variety of travel patterns and is most prevalent in the urban cores of cities. It is the most compact way of serving a dense and large central area.

C. Nodal

A multi-centered network with many transfer centers or "hubs" were routes converge is known as a nodal network. It resembles a collection of small radial networks that serve many activity centers in a region. This system can serve many origin-destination patterns within a localized area without a passing through the CBD. It is possible to coordinate arrivals and departures at the hubs to minimize transfer time. This network concept predominates in the airline industry where several large hubs operate as collection and transfer centers. The airline operates large planes between hubs and smaller planes to and from smaller market cities.

D. Feeder services

Feeder routes link inaccessible residential areas or recent settlements on the periphery to main transport routes. It is also the local distributor in areas not served by conventional public transport. Feeders are analogous to the tributaries of a large river system.

E. Trunk line services

Main line routes are high-capacity corridors that are fed by smaller lines. These typically work well in a linear city with dense corridors.

F. Direct, long distance services

These are typically express service from areas where the formal sector supply is sparse. They may also circulate and distribute in the central area.

5.3.2 Mexico City Network

A typical large city contains a combination of all of the above network elements. Mexico City is no exception. Over the years, Mexico City has evolved from a radial monocentric system into a multinodal and feeder network servicing the changing travel patterns in the

[115] Sussman (2000)

region. Prior to 1969, a bus-based transit network served and reinforced radial routes on a monocentric network structure. Since the opening of the Metro, however, it has been the combination of the Metro and colectivo systems that has shaped the urban form of Mexico City.[116] Colectivo route associations often alter their network of routes and branches to serve new and growing markets, thereby maximizing profits. Sometimes these adaptations bring colectivos in direct competition with the Metro and bus networks.

Figure 5-8 illustrates the major corridors (with >50,000 vehicles per day) in both 1994 and projected in 2020. These diagrams show a continued dominance of the central city in the future but a marked intensification of traffic on several radial and peripheral corridors. This is consistent with the development of several large activity nodes with their own sub-network of radial routes forming a more polycentric city.

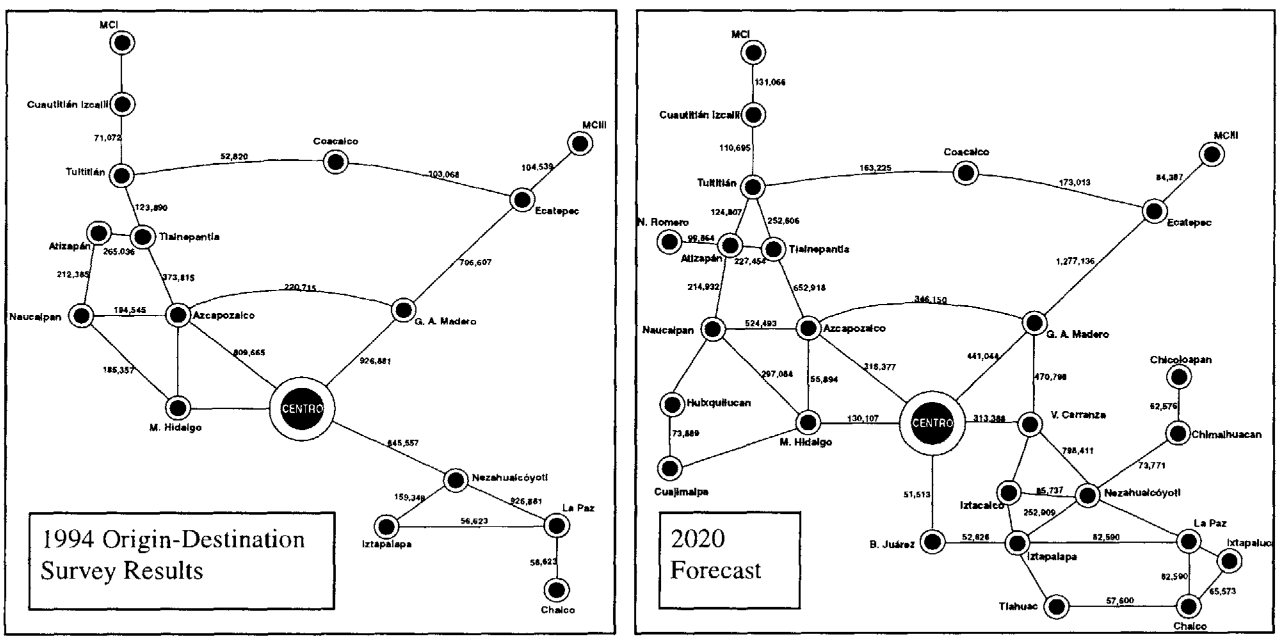

Figure 5-8: MCMA Transportation Corridors (with >50,000 vehicles/day)[117]

The decentralization of Mexico City described in Chapter 1 is changing the daily travel patterns as a large number of people living in the EM travel to work in the DF. As of 1994, 20% of all trips were between the DF and EM as shown in Figure 5-9. This

[116] Cervero (1998)
[117] Source: SETRAVI (1999), Chapter 2, pp. 15-17.

percentage will grow as the population of the MCMA continues to shift from the DF to the EM. The limited road network connecting the two areas, coupled with institutional tensions between these jurisdictions, generates a great deal of congestion and intermodal transfers. For example, 35% of all trips in 1994 involved more than one mode according to the INEGI origin-destination study for the MCMA. The busiest Metro stations are terminals near the border with the EM such as Indios Verdes or Pantitlan. Yet, the Metro network has only recently begun to expand into the EM. Many of these terminal stations are well-served by numerous colectivo routes extending into the farthest reaches of the metropolitan area. Poor people living in the EM often take colectivos to Metro terminals at the border with the DF, and then take the Metro into the city center. Figure 5-10 is a photograph of colectivo microbuses waiting for passengers to surface from the Indios Verdes Metro terminal below ground. Hundreds of these vehicles serve this massive station every day.

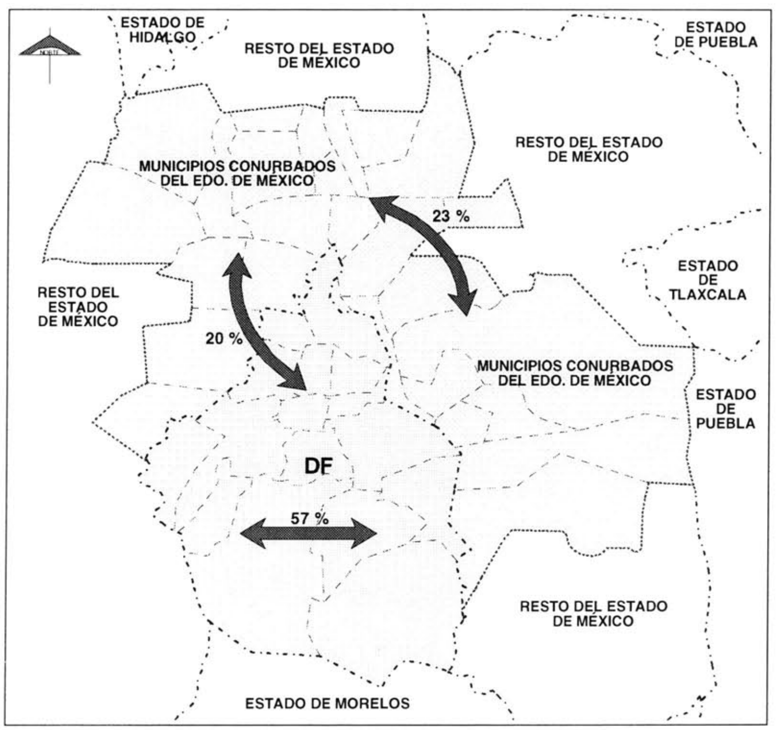

Figure 5-9: Origin-Destination Splits between DF and EM, 1994

Source: COMETRAVI (1999) v.1

Figure 5-10: Colectivos at the Surface of the Indios Verdes Metro Station

The intermediate public transport system, therefore, serves to extend the reach of the Metro network by collecting and distributing riders to its stations. As a result, colectivos are often viewed as a secondary transport network which is driving the urban sprawl of Mexico City. At the release of the last Metro master plan, a key Mexican environmentalist even commented that "expanding the Metro is the surest way to urban sprawl. The further out the lines are run, the broader the secondary transport web."[118]

With respect to road-based public transport, Table 5-3 compares the current network characteristics of the DF public bus company, RTP, with that of colectivos. Several major changes have been proposed to the RTP system. Most notably, SETRAVI plans to redesign the RTP network and add 500 new buses by the end of the year with a commitment for even more in the coming years. Of about 90 Metro stations with bus and colectivo service, 29 are recognized as intermodal transfer centers (known as CETRAMs or "paraderos") with access to major roadways and adequate facilities for users and operators. The growth in public transportation trips over the years has saturated most of

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[118] Miguel Valencia Mulkai, President of the Mexico City Regional Ecology Forum, as cited in Cervero (1998)

these facilities and the congestion is further exacerbated by the proliferation of informal commerce, long dwell times of taxis and colectivos waiting for passengers, and side-street storage of vehicles during the off-peak hours. These centers are administered by SETRAVI, which plans to rationalize them in accordance with the redesign of the RTP bus system, establish alternative transfer points, and promote investment from public and private sources.[119]

Table 5-3: Comparison of Public Bus and Colectivo Networks

	RTP[120]	Colectivos in DF
Number of Vehicles	860 buses (+200 recent additions)	Approx. 28,000
Average age	13 years	8 years
Terminals	7	--
Authorized Routes	72	114
Provisional Routes	24	Several hundred branches
Routes Ending at Metro Stations	75	60%
Routes Through Metro Stations	12	
Estimated Daily Passengers	500,000	> 10,000,000

5.4 Institutional Integration

As a large, multi-jurisdictional region, the Mexico City Metropolitan Area struggles to achieve coordination among government entities. There is a recognized need to integrate transportation and environmental plans by incorporating disparate objectives and parties in a process. Table 5-4, adapted from Nappi Makler (2000), describes the key members of the MCMA's regional architecture for issues of air quality, transportation, and urban development. Pendleton (1998) describes a regional architecture as a framework that illustrates how various institutions will interact to provide an integrated series of transportation services in a metropolitan region. Nappi Makler (2000) extends the established framework to the provision of environmentally-based transportation planning in his thesis. He applies the expanded framework in the context of Mexico City and in

[119] Presentation by Florencia Serrania, SETRAVI, on 9 March 2001 at El Colegio de México.
[120] Ibid.

the process demonstrating some of the problems of the current institutional arrangement. He concludes that in using regional architectures as a tool, emphasis should be placed on five key levels of interaction among the concerned institutions: (1) goals, (2) needs, (3) funding, (4) approval, and (5) data.

Table 5-4: Key Members of the MCMA's Regional Architecture

	Distrito Federal	**Estado de México**	**Metropolitan**	**Federal Government**	**Other**
Air Quality	Secretariat of the Environment (SMA)	Secretariat of Ecology (SE)	Metropolitan Environmental Commission (CAM)	Secretariat of the Environment and Natural Resources (SEMARNAT)	Multi-lateral lending agencies (World Bank, Inter-American Development Bank)
Transportation	Secretariat of Transport and Roadways (SETRAVI), STC, STE	Secretariat of Communications and Transport (EM-SCT)	Metropolitan Commission on Transport and Roadways (COMETRAVI)	Secretariat of Communications and Transport (SCT)	Multi-lateral lending agencies, Route Associations
Urban Development	Secretariat of Urban Development and Housing (SEDUVI)	Secretariat of Urban Develop. and Public Works (SEDUOP)	Metropolitan Commission on Human Settlements (COMETAH)	Secretariat of Social Development (SEDESOL), Bank of Public Works (Banobras)	Private Developers
Other	Delegaciones	Municipios			

Source: Nappi Makler (2000)

In a recent presentation, Arnold Howitt, executive director of Harvard's Taubman Center for State and Local Government, identified two dimensions to the divisions of sub-national governments— vertical and horizontal.[121] First, governments often exhibit vertical fragmentation where multiple levels of government divide authority and responsibilities creating many potential stop points. In essence, no one entity is completely in charge of the policy issue. Regional institutions charged with coordination at the metropolitan level are often the lowest and weakest element of such a government hierarchy. This is the case of COMETRAVI in Mexico City. Second, horizontal fragmentation can exist between peer agencies and organizations, which may be only

[121] Presentation by Arnold Howitt, KSG Taubman Center, on 2 May 2001 at MIT.

loosely coupled by government oversight. Examples of this are the weak linkages between transport, air quality, energy, and land use agencies in the Mexico City government where in reality these subsystems are quite interrelated.

A recent development in Mexico City is the formation of a multi-body Cabinet of Sustainable Development, which includes COMETRAVI, CAM, COMETAH and several other representative bodies from the DF and EM.[122] This development is a step towards responsible and truly coordinated planning. However, Mexico City is still well short of true metropolitan governance. The details of such a plan is beyond the scope of this thesis but a more extensive treatment can be found in Nappi Makler (2000).

5.5 Potential Impact of Integration on Emissions

The potential environmental benefits of greater transit service integration is difficult to measure because it is often indirect. Perhaps the greatest potential in reducing vehicle emissions is by reducing the need for private vehicle trips and the associated road congestion with improvements in public transportation service. This presumes that those with a choice to ride or drive a private vehicle would consider using public transport. In Mexico City, there are very few "choice" riders of public transportation often because of issues related to safety, security, and convenience compared with private modes of transport.[123] By diversifying public transportation options according to price and quality of service, however, it may be possible to attract a larger share of choice riders.

In general, transit networks can become more efficient by minimizing the total travel time of and the VKTs required completing a desired trip for all passengers. This decrease in VKTs can translate into moderate reductions in the transportation services needed and the emissions of transit vehicles. Integration strategies, such as free transfers between modes, may also improve the ratio of PKT to VKT of transit vehicles (i.e., the occupancy). Raising the occupancy of the least-polluting modes of transportation is

[122] Presentation by Florencia Serrania, SETRAVI, on 9 March 2001 at El Colegio de México.
[123] COMETRAVI (1999) v.1

another method to reduce emissions. Therefore, by minimizing circuitous routes and long transfers while maximizing vehicle occupancies, a transit system can potentially reduce emissions significantly.

Finally, fare integration between modes could have an impact on emissions. By increasing the connectivity of separate networks, travelers are more likely to use less-polluting public transport vehicles to complete their journeys. Unlimited ride fare instruments, which provide zero marginal cost for additional public transport trips, may increase ridership and decrease the use of private vehicles. However, this measure may also induce more overall transit trips that may offset some of the private vehicle emission reductions.

5.6 Integration Strategies for Mexico City

The World Bank (2000) identifies two key economic distortions that have contributed to the explosion of informal services in the form of small transit vehicles in some developing world cities. First, there is often an excess supply of labor in urban areas co-existent with minimal public sector wage rates and inefficient operation for the formal public transportation. Second, in the absence of any pricing system for the use of scarce road space giving priority to high-occupancy vehicles, a small informal transit vehicle is better able to provide a faster and sometimes cheaper service than the formal operator. In light of this and the analysis previously described, two key levers are evident in the integration of public transportation modes in Mexico City— fares and rights-of-way. The following paragraphs describe strategies that utilize both as well as other supporting measures in the Mexico City context.

5.6.1 Public Transport Fares

Intramodal and intermodal transfers are a key element of the current public transportation system in the MCMA since more than one-third of transit riders rely on transfers to maximize the origins and destinations available to them.[124] Therefore, fare coordination may be an extremely important strategy. The lack of fare integration between the Metro and the bus or the trolleybus system is one of the reasons that the government-operated modes have lost mode share to colectivos, which can often provide more direct service for a fare premium. The lack of system integration also leads to pervasive system inefficiencies that diminish the overall quality of transportation services by making trips longer and more inconvenient. This has a negative impact on the ridership of the least polluting modes.

The best fare policies should encourage travelers to use the most efficient routes to reach their destinations. At present, many poor workers who use colectivos, buses, and the Metro have to transfer three to five time from their origin to their destination.[125] The lack of free transfers raises the cost of such intermodal trips and makes public transportation modes appear entirely independent systems. Having a single transit provider, in general, facilitates fare integration. Having many different modes and providers often creates resistance to fare integration because of potential revenue losses in the short run. However, in the long run, uncoordinated fare policies can lead to inefficient or duplicative network structures which do not benefit anyone.[126] Some evidence of this can be seen in the competition between publicly-operated (e.g. the Metro) and privately-operated transit modes (e.g. the colectivos) in Mexico City.

By simplifying and reducing the cost of intermodal and intramodal transfers, a transit agency can attract new riders and encourage existing customers to ride more frequently. New York City is perhaps one of the best examples of how fare integration can increase ridership by improving the level of service and providing free transfers. The transit agency introduced the *MetroCard* in the mid-1990s and free transfers in 1997 between the subway and buses, for both public and private operators.

[124] 1994 MCMA Origin-Destination Study, INEGI.
[125] Cervero (1998)
[126] Lee (2000)

Between 1997 and 2000, New York experienced double-digit percentage growth in ridership for both subway and bus, peak and off-peak, and weekday and weekend.[127] There were also significant increases in feeder bus trips to subway stations. Although much of these results were derived from the offering of free intermodal transfers, electronic fare media can facilitate, or at least simplify, the process toward true fare integration between all modes, public and private. For example, one can envisage implementing a magnetic stripe or contactless "smart card" that a customer could use with any participating colectivo, as well as the Metro and RTP bus systems. It is conceivable that these cards could also be used in public phones, vending machines in terminals, parking payment, or even as a college campus identification. Private operators could then be electronically remunerated for the smart card trips they served. The advantages enjoyed by the participating colectivos once these cards are in wide distribution would likely encourage all colectivos to join and conceivably force them to conform to certain minimum requirements and standards set by the government authority.

Similar plans are now taking shape in Mexico City. According to a recent Mexico City newspaper article, the Director of the STC and the Metro, Javier Gonzalez Garza, has initiated negotiations with banks and telephone companies to jointly develop an electronic or "smart" card that could be used as a fare instrument for the Metro, make telephone calls, or access automatic teller machines.[128] The Metro wishes to share the costs and have the new cards be widely accepted. Many of these banks and telephone companies have ample experience with this type of technology. Some of the banking institutions have demonstrated interest in the idea in order to expand their market into new segments of the economy. The advantages of such a system identified by the Metro are greater control over fares, elimination of certain problems such as making change or the long lines at peak hour at ticket booths. The Metro is currently analyzing the technological possibilities for the new system, which would initially operate alongside the current system of small magnetic strip tickets. Each card has an approximate cost of 20 pesos (US$2.00). Perhaps a bigger issue is the cost of changing the current system of

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[127] Hirsch (2000) as cited in Lee (2000)
[128] *La Reforma* newspaper article. "Busca Metro tener boletos electronicos." 19 March 2001.

1,750 turnstiles in all 11 lines of the Metro to one compatible with the new fare instruments. There are also discussions with the SETRAVI of implementing the same system in the RTP bus network to create true intermodal fare integration.

The subsidy of public transportation in Mexico City is a tool used to influence travel choices and promote social objectives such as affordable transportation for lower-income people who do not own a private vehicle. However, subsidies can also be a source of economic distortion that negatively impacts system efficiency by reducing the incentive to lower costs. Many observers believe that this led to the downfall of Ruta-100. Mode share data from Mexico City shows that people are willing to pay more to use the unsubsidized colectivos in exchange for better service rather than use the subsidized public transport, which often provides worse service. By creating a true intermodal system, the Metro and bus systems can capture more of the public's willingness to pay for a high-quality service.

5.6.2 Rights-of-Way

In the absence of a reasonable road-pricing scheme, controlling the use of public infrastructure in favor of high-occupancy modes is potentially a useful strategy. Specifically, by giving a visible and significant priority to higher-capacity modes with lower emissions per passenger (e.g., new buses over old microbuses), significant improvements in both emissions and the mobility of transit riders can be expected. However, as the results of the corridor model show (Chapter 3), dedicating existing lanes to public transportation necessarily increases the congestion on the remaining mixed-traffic lanes and the travel time for those users. Overall, the net effect on mobility and emissions for the corridor depends on numerous parameters such as the mode split of private and public transportation trips and if a lane is added or taken away.

The corridor model also shows that highly-congested corridors may benefit from the physical segregation of public transportation modes from other low-occupancy vehicles. The logical argument for this is that as household incomes rise, the average trip length and number of trips per household increases. People do this to increase or sustain their lifestyle, social, economic, and educational opportunities. As people grow wealthier, their time becomes more valuable and they tend to increase the speed of their travel to compensate.[129] Therefore, income is a major driving force for higher automobile ownership rates and use. As a result, the best way to make public transportation competitive with the private automobile is to increase its speed or decrease the door-to-door travel time of its users.[130] In other words, giving public transportation a competitive advantage in the form of exclusive rights-of-way is one of the best ways to make public transportation attractive to private vehicle users. This also has been shown to have the side benefit of reducing operating costs after the initial capital investment is made. As shown in Chapter 3, however, the overall impact of exclusive busways on emissions may be positive or negative depending on the amount of additional congestion created in the mixed-traffic lanes.

Moving towards the pricing of transportation services by their true costs is also an effective method of encouraging cost reductions. This strategy, however, is limited by conflicts with socially-oriented objectives such as subsidizing services for the poor and disabled. Nonetheless, one can envisage the tendering of public transportation routes with a dedicated right-of-way to private operators based on a "usage fee" contract.[131] In essence, this concept would involve is a periodic payment made to the public entity that owns the infrastructure and land. The method of establishing a minimum price could be based on a number of criteria such as a percentage of the total discounted revenue stream projected into the future, service frequency, and the emissions characteristics of the vehicles to be used. There are several benefits to this arrangement. First, competitively awarding such a contract to the qualified bidder with the highest offer would, in principle, ensure that the most efficient and highest-capacity modes utilize the infrastructure. Second, the public sector can offset some of its expenditures from reconfiguring the infrastructure from the proceeds. Third, the fees can be use to perform proactive maintenance to infrastructure. Lastly, some portion of the fee can be used to pay for the

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[129] Schafer and Victor (2000)
[130] Based on interview with Matthew Jordan-Tank, Inter-American Development Bank, July 2000.
[131] Ibid.

administrative costs of the regulatory agency, which will require technical staff, monitors, and possibly traffic police. It is important to note that no arrangement with an exclusive right-of-way may work unless enforcement is adequate.

5.6.3 Other Supporting Measures

1. Economic Incentives

There may be significant benefits from constructing economic incentives for the integration of transit services. For instance, since cheap labor has been identified as a major factor in the dominance of the small, informal transit units, it is conceivable that significantly improving the wages of drivers of formal bus companies (both public and private) would reduce the latent demand for jobs in the informal sector. Of course, this strategy contains a very tangible cost which would ultimately have to come from higher fares or a government subsidy. However, the benefits may outweigh the costs in the long-run because these formal bus companies could operate in a well-regulated and integrated manner that reduces the externalities associated with the informal sector.

2. Improving System Integrity and Legibility

There may be significant mobility benefits from improving system integrity and legibility through both low-cost measures and more significant structural changes. Legibility refers to how easily a public transportation system can be understood from a map or at the street level. Factors that determine system legibility include available public information, signs, and the network design itself. Low-cost measures include developing a meaningful color scheme and marketing a clear message for road-based transit vehicles. This is the case in Curitiba where numerous private companies operate the urban bus system with a very strong emphasis on public image, color-coded line and routes, and a single logo. The idea is to make private and public transit vehicles appear indistinguishable to the user, both inside and outside. Real-time information and data management can also significantly improve the integrality of a system and the level of service without increases in vehicle frequencies. These measures become even more effective as the per capita income, and therefore the value of time, of passengers increase.

3. Strategic and Integrated Regional Transportation Planning

Strategic regional transportation planning in Mexico City should identify, develop, and integrate the role of each mode to effectively support the economic activity of the region while minimizing the environmental and social externalities. Specifically, it should recognize the advantages of colectivos in poor, and inaccessible markets and extending the coverage and frequency of the public transportation system. It should also include non-motorized modes (i.e., walking and biking) in all planning processes. Evidence from other major Latin American cities shows that a significant portion of trips is made on foot. In São Paulo and Santiago de Chile, for example, the share of all trip segments made on foot is estimated to be between 20-30%. There is evidence that walking is also a major mode in Mexico City, particularly for the poor.[132] It is also important to note that nearly all transit trips begin and end with a complementary walking trip. In light of this, an integrated public transportation plan could never be so without considering non-motorized travel. A strategic transportation plan for MCMA could also address the reorganization of intermodal services and transfer facilities (CETRAMs) to minimize the total travel time of users considering transfer times.

4. Public-Private Partnerships

Public-private partnerships could be a model of institutional integration in public transportation. Perhaps the best example is from Curitiba, Brazil, where the city and state governments worked closely with a leading bus supplier (Volvo) in developing its renowned integrated transit system for this city of 2 million. In fact, as a result of the partnership, a Volvo manufacturing plant was consequently constructed near Curitiba. In a recent corporate presentation by the president and CEO of the Volvo Group[133], the firm plans to market total mobility solutions to cities, such as the innovative bus system in Curitiba, and has identified environmental sustainability as a corporate strategy. Volvo is one of the largest bus and truck manufacturers in the world and a leader in emissions technology.

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[132] Based on a presentation by Martha Schteingart, Professor of Urban Planning at El Colegio de México, on 1 May 2001 at MIT.

[133] Presentation by Leif Johansson, Volvo Group President and CEO, at MIT on 9 April 2001.

Another example is from September of 1999, when two transportation agencies in Mexico City— the "Coordinacion de Transporte de Mexico" and "Ruta 89 Union de Taxistas Camesinos Libres Independientes"—contracted with a private firm to convert 4,100 public transportation vehicles from gasoline fuel to liquid propane gas. There were plans eventually to convert 70,000 commercial vehicles in the city to liquid propane.[134] A final example is SETRAVI's plan to stimulate public and private investment in services and sanctioned commerce at the intermodal stations of the DF (CETRAMs).

5.7 Conclusion

Public transportation authorities in Mexico City have two main controls at their disposal—fares and rights-of-way. This chapter identified numerous strategies that maximized the use of these and others powerful influencers towards enhancing the integration of transit services. By integrating public transportation modes, networks, and institutions, it is believed that improvements can be achieved in both mobility and transportation-related emissions in the MCMA. The next and final chapter is the conclusion of this thesis that summarizes the key finding and areas of potential future research.

[134] http://www.eia.doe.gov/oiaf

Chapter 6. Conclusions

6.1 Summary

The Mexico City Metropolitan Area (MCMA) is one of the largest metropolises in the world with a population of almost 18 million. As in other large cities of the developing world, many of its residents suffer from high levels of congestion, pollution, poverty, poor infrastructure, and other problems exacerbated by political and institutional barriers. At the same time, Mexico City is the economic engine of a growing Mexican economy. As such, many observers characterize Mexico City as one of the handful of "mega-cities" in the world. The notion that the problems of these cities with more than 10 million inhabitants are distinctly different from smaller cities is debated by some. However, the question remains— are there aggregate diseconomies of scale in very large cities, or is there a balance of both positive and negative aspects in reality? There is little debate that the institutional complexity and political barriers have increased substantially as Mexico City grew in the second half of 20th century. Nonetheless, the problems and their causes may be more manageable because of the greater availability of resources, focus of national and regional political attention, and concentration of talent, wealth, and institutions for innovations compared with other areas.[135] This is particularly the case in the *Distrito Federal (DF)* with respect to the poorer surrounding municipalities in the *Estado de México (EM)*.

Mexico City was once renowned for beautiful mountain vistas; yet, today it is infamous for high levels of air pollution exacerbated by the high altitude (around 2,200 meters above sea level) and mountains surrounding the city on three sides. Exposure to airborne pollutants such as nitrogen oxides (NOx), carbon monoxide (CO), volatile organic compounds (VOC), sulfur dioxides (SOx), particulate matter (PM), and ozone have both direct and indirect impacts on human health and the quality of life. In addition, recent

[135] Based on personal communications with Prof. Ralph Gakenheimer, Dept. of Urban Studies and Planning at MIT.

scientific research concludes that low-atmosphere ozone in Mexico City may be constrained by NOx levels rather than VOCs.

The largest contributors to total emissions in the MCMA are mobile sources. At the same time, the transportation of people and goods are key components in the broad context of Mexico City's socio-economic and environmental systems. In light of this, road-based transportation including automobiles, buses, colectivos, taxis, and trucks are part of the air pollution problem and an essential element of human activity in Mexico City. Changing the supply of transportation services has significant implications on the demand and personal mobility of residents. However, transport-related strategies can reduce emissions from motor vehicles. For example, improved public transportation could divert existing trips or absorb future trips on low-occupancy modes like private automobiles. Public transportation, including buses and colectivos, currently contributes to about 12% of all emissions while carrying the majority of passenger trips in the region.[136]

Air pollution is not the only transportation-related externality of concern in Mexico City. As other cities in the developing world, Mexico City suffers from high levels of noise pollution, and high rates of traffic accidents and fatalities compared to the developed world. The cost to society of all these externalities is difficult to measure, but is undoubtedly high and cannot be ignored by decision-makers.

6.2 Perspectives on the Colectivos

The privately-operated *colectivos* are the dominant mode of public transportation in Mexico City. They can be viewed from two distinct perspectives— one "half-empty", the other "half-full". In the former, the colectivo is a low-capacity form of public transportation that undermines the more formal transit modes, like urban buses and the Metro, and leaves much to be desired in the way of safety, maintenance, and a poor

[136] Based on CAM 1998 Emissions Inventory for the MCMA and COMETRAVI (1999)

image for one of the world's largest cities. Their competitive nature promotes unsafe operating practices, congestion, and ultimately air pollution. On the other hand, the latter perspective views colectivos as a high-occupancy, intermediate public transportation mode that provides essential mobility to millions of Mexico City residents daily, particularly on the periphery of the region. They simultaneously enable and adapt to the growth of the city in population and size without a government subsidy. Their users are, in many cases, "voting with their feet" by choosing the colectivo over other forms of public transportation even when those other modes are available. .

These two perspectives represent the two most prevalent opinions in Mexico City today concerning the colectivo. The first opinion is shared by most government officials and automobile users who favor imposing stricter regulations and restrictions on the colectivos. This would include replacing the microbuses with full-size buses and route associations with formal companies. The second opinion is primarily held by thousands of colectivo owner-operators and implicitly by the travel choices of the majority of low-income people in Mexico City. It is supported by the ability of the private sector in the form of colectivos to operate a frequent service with no direct government subsidy. The market responsiveness of colectivos has allowed them to adapt with the rapid growth of the city over the years. The best examples of this adaptation are the evolution of vehicles from sedans to microbuses in the last couple of decades and the development of fixed routes on some of the busiest corridors in Mexico City. In fact, the growth and market agility of the colectivo transportation sector has enabled much of the growth in land area and economic opportunities in the MCMA.

6.3 Key Findings

6.3.1 Corridor Modeling

In this thesis, a *corridor model* was developed and is described in Chapter 3. The modeling and analysis shows that no single public transportation strategy is likely to improve both mobility (as measured by total travel costs) and emissions by more than 5% each. In fact, the corridor model predicts that most individual strategies present a win-lose or lose-win tradeoff between mobility and emissions. For example, reserving (i.e., taking away) an existing lane on a high-demand corridor and dedicating it to public transportation use is potentially a win-lose or lose-win strategy depending on the level of congestion. On the other hand, installing a new lane for public transport is beneficial to both emissions and mobility. This analysis, however, does not consider the induced demand from freeing up extra capacity on the mixed lanes. The latent demand for road space is potentially very high in Mexico City.

The corridor model also shows that replacing colectivo microbuses with full size buses as planned by SETRAVI would reduce emissions significantly. Nevertheless, this strategy may also reduce mobility by increasing the wait time and the total travel costs, especially in uncongested conditions. Furthermore, replacing microbuses with full-size buses and reserving an exclusive lane on a congested corridor for their use may not improve emissions or total mobility along the corridor. However, this combined strategy may ease the opposition to such a substitution program because it minimizes the loss in profits for the participating colectivo owner-operators. In general, the results of the corridor model are highly dependent on the modal mix of a corridor and other operating characteristics and, therefore, the numerical results should not be applied directly.

6.3.2 Regulation and Competition of Public Transportation

Road-based public transportation in Mexico City is loosely regulated and the vast majority of all vehicles in this sector are privately owned and operated. Private participation in road-based public transportation in Mexico City is likely to continue. The reform of government regulations to improve the public transportation system in Mexico City may be enhanced by a number of strategies described in Chapter 4. These regulatory-based strategies are grouped into four key categories and are summarized below.

1. Facilitating Implementation

The introduction of a new regulatory scheme should be a gradual and public process to allow for negotiation and coalition building. Nevertheless, restructuring of regulations can serve as a resetting mechanism to address some of the chronic ills of a public transportation system. Specifically, minimizing the time lag between higher fares and service quality improvements is key implementation strategy. In addition, developing two-way public-private partnerships may also facilitate planning and implementation.

2. Long-Term Sustainability

Minimizing the number of potential losers, while maximizing the number of those who may benefit, maximizes the likelihood of acceptability and long-term sustainability of regulations. Contingency plans, government transparency, contract and traffic enforcement are also essential to ensure long-term sustainability. In addition, competition should be viewed as a biological phenomenon that must grow and be maintained. In this manner, a new regulatory system can be improved in the long-term by fostering a local professional base to maximize participation of qualified bidders in procurement processes. Where route associations do not currently exist, it may be beneficial for the regulatory agency to assist in developing formal associations that provide a minimal level of organizational structure. The procurement process for competitive concessioning of routes should be done in two-steps— a qualification phase and a bid phase.

3. Optimizing the tradeoffs between level of service and costs

Splitting public transport functions can help isolate political pressures, capture private entrepreneurship in operation, and the maximize the efficiency of coordinated planning. In addition, holding concessionaires financially accountable to public satisfaction can improve the quality of public transportation services.

4. Balancing Mobility and Environmental Objectives

There are two key functions for public transportation in Mexico City— providing personal mobility for economic development while minimizing vehicle emissions to improve air quality and health. Metropolitan governance should be aligned with these regional objectives. Specifically, coordination and cooperation between government agencies can facilitate in concurrently planning for environmental and mobility improvements. Finally, technological innovations have been and will likely continue to be integral to air quality improvement strategies in Mexico City. These include not only vehicle control technologies, but technologies that improve the level of service of public transportation.

6.3.3 Integration of Transit Services

Chapter 5 describes three levels of integration for public transportation services in Mexico City— modal, network, and institutional— and the possible impact of such integration strategies on mobility and emissions. First, modal integration involves making the most of the mix of modes and vehicles by recognizing the advantages and disadvantages of each. Colectivos currently have a very important role in Mexico City serving the majority of public transportation trips, especially on the periphery of the region. In the future, colectivos may also be integral to diversifying public transportation services by level of service and cost. The best example of this is the high quality microbus service in Porto Alegre, Brazil which attracts higher-income commuters by offering conveniences comparable with the private automobile. Second, network integration denotes reinforcing the currently informal "hierarchical" network structure to minimize the cost and travel time of travelers. This can be achieved in a number of ways including the contracting out of feeder services, and free intermodal and intramodal transfers, and joint fare instruments such as "smart cards". Finally, institutional integration would involve greater cooperation between federal, DF, and EM entities on regional issues such as the management of transportation and air pollution.

6.4 Conclusions

In the recent scenario analysis effort for the Mexico City project described in Chapter 5, the number of passenger trips in the MCMA is projected to increase by 76% over the next two decades.[137] Coupled with a marked shift towards private automobiles, the result

[137] Refers to the scenario analysis presentation by the faculty and students of the MIT Integrated Program

could be a doubling of emissions from mobile sources. This would have a profoundly negative effect on air quality in the MCMA. Therefore, the challenge for the future is to support the growing mobility needs of the region while improving emissions from mobile sources. As this thesis shows, the better management of road-based public transport through effective regulations and integration strategies may help achieve both objectives.

The growth in automobile ownership and travel in Mexico City is fueled by rising per capita income and economic development. The possible social costs of these extra vehicles and vehicle kilometers traveled (VKT) are congestion, wasted time and energy, air pollution, lost productivity due to accidents, stress, and declining quality of life. High-capacity modes of transportation can reduce emissions and energy consumption per passenger and overall noise pollution in comparison with private vehicles. These benefits are a direct function of diverting trips from low-occupancy vehicles, such as private automobiles, to higher-occupancy vehicles.

In light of this, the real opportunity in the long-term is to improve the quality of service of all public transportation, operated by both the public and private sectors, to attract and retain the emerging middle-class that may one day purchase private vehicles. If incomes continue to increase with the economic development of the country as expected, the real challenge will be to absorb the increasing travel demand with public transportation and lessen the growth of private vehicle trips. This may be achieved with intermediate transportation that offer a level of service, convenience, and speed between that of the automobile and the current public transportation system. Government policies, therefore, should focus on discerning travel preferences by price, enabling the private sector's ability to attract "choice" riders in the future, and maintaining vehicle occupancies high.

With respect to the DF government's plan to substitute the 28,000 microbuses with 8,000 full-size buses over the next few years, the patrons of colectivos in Mexico City are accustomed to high frequency service. In fact, high frequency is what makes much of the

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on Urban, Regional and Global Air Pollution on 9 March 2001 at El Colegio de México, in which the author participated.

current intermodal and intramodal transfers practical for Mexico City commuters. Increasing the vehicle size from microbuses to full-size or articulated buses would necessarily reduce the frequency of service. The key is to offset the increase in wait time with a significant reduction in the travel time (i.e., higher average vehicle speeds) and/or a reduction in the number of transfers and their cost. Perhaps the best way to increase operating speed is by providing exclusive lanes for public transportation modes. Moreover, the best manner of reducing transfer time and cost is by integrating fares and rationalizing the current colectivo system with the other, higher-capacity modes.

Public transport policies for the MCMA must recognize the benefits of colectivos by integrating them effectively with other modes of public transport and harnessing their market responsiveness by promoting other types of transportation service. The Mexico City government may pursue a policy of formally differentiating public transport services with the aim of appealing to a wider segment of the population as per capita income grows in the future. These services could be based on the user's willingness to pay for speed, convenience, and comfort and could be provided by the private sector. In such a system, higher-priced and higher-quality services may succeed in attracting higher-income riders; particularly if dedicated rights-of-way are implemented improving the speed and reliability of service. The government may also choose to pursue advanced transit technologies being developed in other countries that facilitate the implementation of such a policy. Examples of this include electronic fare instruments such as "smart cards" or signal pre-emption systems that approximate an exclusive right-of-way for public transportation. The most significant environmental benefits of improving public transportation with such measures are admittedly indirect but are a means of absorbing the growing mobility needs with public transportation and avoiding increased gridlock and air pollution in the future.

In sum, this thesis show that integrating public transportation modes and networks, implementing public-private partnerships, increasing the quality of transit services, and improving infrastructure and fleet management may be the most useful strategies to reduce motor vehicle emissions while improving mobility in Mexico City. Specifically, the corridor modeling shows that giving priority to public transportation modes with dedicated rights-of-way and investing in new and cleaner vehicles may be effectively combined with a higher-quality, higher-fare service which people will increasing want in the future. As always, public support will be a key in determinant of the success of any transportation strategy.

6.5 Areas for Future Research

The following are recommended areas of future research that may extend the work presented in this thesis and, more generally, the understanding of transportation and air quality in Mexico City.

- In general, there is a need to gather more socio-economic and trip-making data from Mexico City beyond what is available from the synthesis of the 1994 MCMA origin-destination study. There is a particular need for a survey of colectivo operators and a survey of bus and colectivo users. The most important gaps in the available data are related to the number of intermodal and intramodal transfers made by public transportation users, socio-economic characteristics of these users, and the availability of alternative modes of transportation to them. There is also a need for a study of colectivo operators to measure their reaction to certain strategies and gage the feasibility of any future recommendations. Finally, there is a need for more complete and recent corridor data including vehicle counts and passenger counts by time of day and at several locations along major corridors.
- Apply the new data to improve the public transportation mode split model and develop a more complete and sophisticated demand model that considers the split of passenger trips between public (bus and colectivo) and non-public transportation modes (automobile and taxi). This improved model could be used to test the impact of strategies to improve the quality of public transportation service on private vehicle trips.
- Testing numerous combinations of strategies beyond what was done in presented in Chapter 3 using the corridor model.

- Expand the capabilities of the corridor model by including a network of corridors, the interaction between intersecting corridors, and socio-economic and demographic data to estimate demand. Apply the corridor model methodology to 33 major corridors that SETRAVI proposes to improve in Mexico City and estimate the effect on emissions and mobility. Integrate these results with the long-term public transportation sector model developed for the scenario analysis effort to make 20-year projections of emissions for the MCMA. Alternatively, one could apply a transportation planning software package such as TransCAD to model a network of routes and their operations.
- Creating a land-use model to test the theory that an expansion of the Metro network in Mexico City, in combination with complementary adaptation of the colectivo system, generates urban sprawl. In addition, it may be possible to test different "hierarchies" of public transportation systems for the impacts on mobility and emissions.
- Finally, it may be useful to simulate and measure the differences of operating practices of privately-operated public transportation on mobility and emissions. These practices may vary between waiting for a certain number of passengers at terminals and operating a predetermined schedule.

6.6 A Final Word

The author hopes that this thesis is of use to the reader by shedding some light on the complex tradeoffs between mobility and transportation-related emissions. The ultimate hope is that it can be a step towards ensuring a sustainable future for transportation in Mexico City— both for the sake of economic development and the quality of life of its residents.

Appendix A: Detailed Corridor Model Print-outs

The following pages contain detailed print-outs of the following corridor model.

Corridor Test: Varying Demand — 4-lane divided urban arterial (Class II)

	Hourly Peak Demand in One Direction (Pass.-Trips)	Fare ($ Pesos) Bus	Fare ($ Pesos) Col	Vehicle Capacity Bus	Vehicle Capacity Col	Headway Peak (min.) Bus	Headway Peak (min.) Col	Headway Off-Peak (min.) Bus	Headway Off-Peak (min.) Col	Colect. Occup. Col
Data:	5000	$1.00	$1.77	70	35	1.76	0.25	2.21	0.32	85%
SCENARIO 1	3000	$1.00	$1.77	70	35	1.76	1.10	2.21	1.57	85%
2	4000	$1.00	$1.77	70	35	1.76	0.81	2.21	1.16	85%
3	5000	$1.00	$1.77	70	35	1.76	0.65	2.21	0.92	85%
4	6000	$1.00	$1.77	70	35	1.76	0.54	2.21	0.76	85%
5	7000	$1.00	$1.77	70	35	1.76	0.46	2.21	0.65	85%
6	8000	$1.00	$1.77	70	35	1.76	0.40	2.21	0.57	85%
7	9000	$1.00	$1.77	70	35	1.76	0.36	2.21	0.50	85%
8	10000	$1.00	$1.77	70	35	1.76	0.32	2.21	0.45	85%

OPERATIONAL RESULTS

	Pk-Hr Pass. Mode Share (of R.B.P.T. Trips) Bus	Pk-Hr Pass. Mode Share Col	Passengers Per Day Bus	Passengers Per Day Col	Corridor LOS Peak	Corridor LOS Off-Pk	VKT per Year on Corridor Bus	VKT per Year on Corridor Col	Daily VKT per Vehicle Bus	Daily VKT per Vehicle Col	No. of Veh. Operating in Peak Bus	No. of Veh. Operating in Peak Col	No. of Veh. Operating in Off-Pk Bus	No. of Veh. Operating in Off-Pk Col
Data	19.4%	80.6%	10163	42224	B	A	4,700,160	32,762,880	236	337	53	258	36	175
1	25.4%	74.6%	7996	23436	A	A	5,091,238	7,559,251	264	397	46	50	37	35
2	24.7%	75.3%	10341	31568	A	A	5,091,238	10,209,074	264	397	46	67	37	47
3	24.2%	75.8%	12693	39695	A	A	5,091,238	12,855,820	264	397	46	84	37	59
4	23.9%	76.1%	15047	47818	B	A	5,091,238	15,501,108	262	392	48	105	37	71
5	23.7%	76.3%	17402	55940	B	A	5,091,238	18,145,591	256	380	51	136	37	84
6	23.6%	76.4%	19759	64061	C	A	5,091,238	20,789,582	251	369	55	172	37	96
7	23.5%	76.5%	22116	72181	D	B	5,091,238	23,433,250	240	347	59	217	38	113
8	23.4%	76.6%	24474	80301	D	B	5,091,238	26,076,696	226	319	65	273	40	134

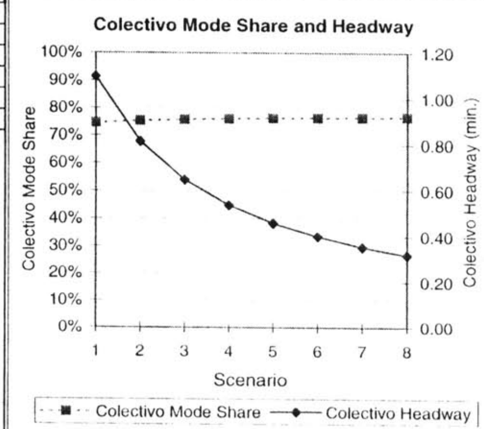
CORRIDOR PARAMETERS:

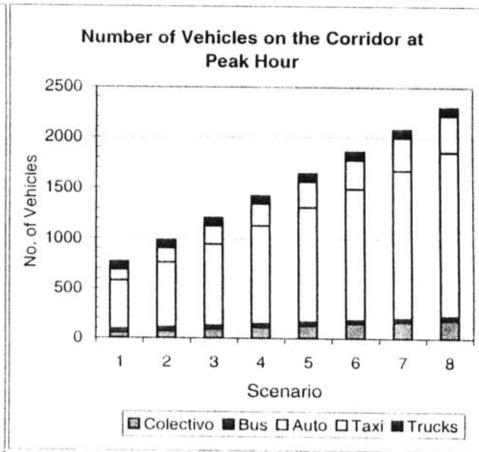
Theoretical Capacity (equiv. veh./hr)	3000	Length, one way (km)	15
Number of Hours in Peak Demand	6	% of Daily Traffic in the Peak Period	42%
Number of Hours in Off-Peak Demand	12	% of Traffic in Peak Direction	55%
% of Hourly Demand during Peak	100%	Avg. Hours of Colectivo Operations/Day	12
% of Hourly Demand during Off-Peak	70%	Number of Colectivo Workdays per Year	320

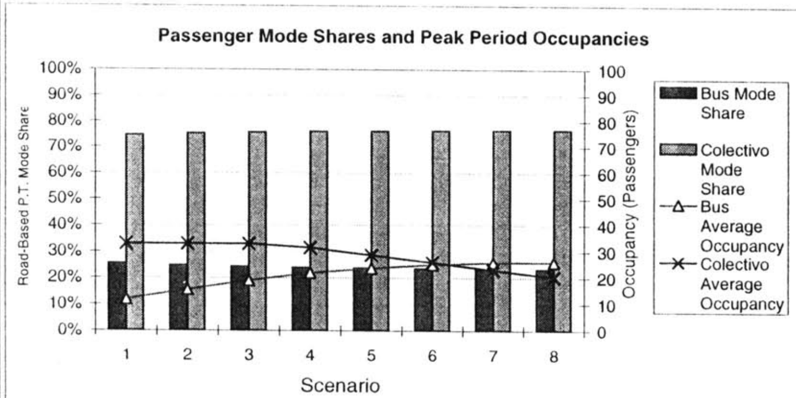
	Auto	Bus	Col	Taxi	Trucks	Total
Observed No. of Veh. (Pk Hr)	817	34	237	182	81	1351
Observed Vehicle Mode Share	60.5%	2.5%	17.5%	13.5%	6.0%	100%
Observed Pass. Mode Share	24.5%	14.1%	58.6%	2.7%	0.0%	100%
Value of Time (Pesos/hr)	$ 15	$ 10	$ 10	$ 15		
Avg. Speed (Kph)	45.6	19.6	29.1	45.6	45.6	
Mixed Lanes	1	1	1	1	1	
Exclusive Lane	0	0	0	0	0	0
Fuel	0	1	0	0	0	0=Gasoline, 1=Diesel

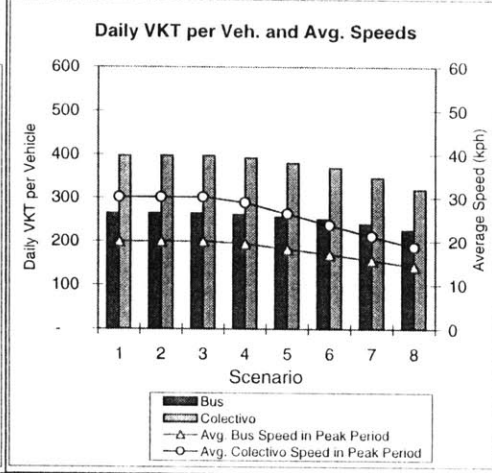
Colectivo Fare Structure and Avg. Trip Length	Trip Km	Fare	Observ.	
	0 - 5	$ 1.50	63.3%	0.950
	5 - 12	$ 2.00	20.4%	0.408
	12 - 17	$ 2.50	6.1%	0.153
	> 17	$ 2.50	10.2%	0.255
	Total		Avg. Fare	$1.77

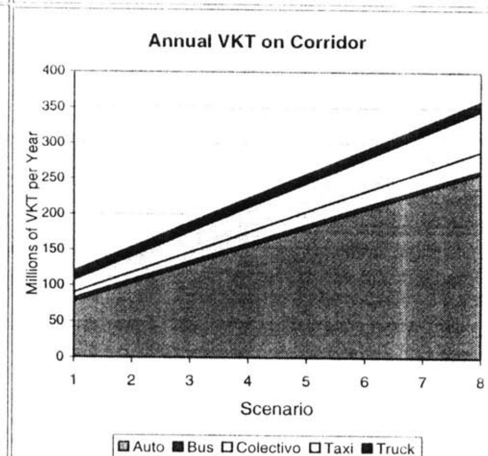
Distance	
5	3.165
12	2.448
17	1.037
17	1.734
Avg. Dist.	8.4











Corridor Test:	Varying Demand	4-lane divided urban arterial (Class II)

	Hourly Peak Demand in One Direction (Pass.-Trips)	Fare ($ Pesos)		Vehicle Capacity		Headway Peak (min.)		Headway Off-Peak (min.)		Colect. Occup.	Total Daily Costs (All Modes & Both Dir.)	Daily Delay in Pk. Dir. (hrs.)	Operational Cost per Veh. Per Day		Revenue per Veh. Per Day		Fleet Profitability per Day		Profit Per Vehicle Per Day		Profit/Loss Margin	
		Bus	Col	Bus	Col	Bus	Col	Bus	Col	Col			Bus	Col	Bus	Col	Bus	Col	Bus	Col	Bus	Col
Data:	5000	$1.00	$1.77	70	35	1.76	0.25	2.21	0.32	85%	$ 682,086	12,787	$ (2,054)	$ (1,008)	$ 297	$ 446	$ (109,298)	$ (170,580)	$ (1,757)	$ (562)	-85.5%	-55.7%
											-44.7%	581.3%					-14%	2%	-26%	-76%		
SCENARIO 1	3000	$1.00	$1.77	70	35	1.76	1.10	2.21	1.57	85%	$ 377,244	4,392	$ (2,141)	$ (1,106)	$ 242	$ 1,264	$ (114,481)	$ 9,381	$ (1,900)	$ 158	-88.7%	14.3%
2	4000	$1.00	$1.77	70	35	1.76	0.81	2.21	1.16	85%	$ 500,778	5,800	$ (2,141)	$ (1,106)	$ 310	$ 1,264	$ (110,362)	$ 12,669	$ (1,831)	$ 158	-85.5%	14.3%
3	5000	$1.00	$1.77	70	35	1.76	0.65	2.21	0.92	85%	$ 624,325	7,209	$ (2,141)	$ (1,106)	$ 379	$ 1,264	$ (106,225)	$ 15,954	$ (1,763)	$ 158	-82.3%	14.3%
4	6000	$1.00	$1.77	70	35	1.76	0.54	2.21	0.76	85%	$ 758,994	9,127	$ (2,134)	$ (1,098)	$ 443	$ 1,247	$ (102,800)	$ 18,483	$ (1,690)	$ 150	-79.2%	13.6%
5	7000	$1.00	$1.77	70	35	1.76	0.46	2.21	0.65	85%	$ 916,888	12,110	$ (2,117)	$ (1,079)	$ 501	$ 1,210	$ (100,344)	$ 19,622	$ (1,616)	$ 132	-76.3%	12.2%
6	8000	$1.00	$1.77	70	35	1.76	0.40	2.21	0.57	85%	$ 1,090,882	15,831	$ (2,099)	$ (1,060)	$ 555	$ 1,174	$ (98,015)	$ 20,103	$ (1,544)	$ 114	-73.5%	10.8%
7	9000	$1.00	$1.77	70	35	1.76	0.36	2.21	0.50	85%	$ 1,311,619	21,693	$ (2,065)	$ (1,023)	$ 594	$ 1,103	$ (97,678)	$ 16,785	$ (1,471)	$ 79	-71.2%	7.8%
8	10000	$1.00	$1.77	70	35	1.76	0.32	2.21	0.45	85%	$ 1,584,138	29,927	$ (2,022)	$ (979)	$ 619	$ 1,016	$ (98,803)	$ 9,554	$ (1,403)	$ 37	-69.4%	3.8%

ECONOMIC RESULTS

CORRIDOR PARAMETERS:

Theoretical Capacity (equiv. veh./hr)	3000	Length, one way (km)	15
Number of Hours in Peak Demand	6	% of Daily Traffic in the Peak Period	42%
Number of Hours in Off-Peak Demand	12	% of Traffic in Peak Direction	55%
% of Hourly Demand during Peak	100%	Avg. Hours of Colectivo Operations/Day	12
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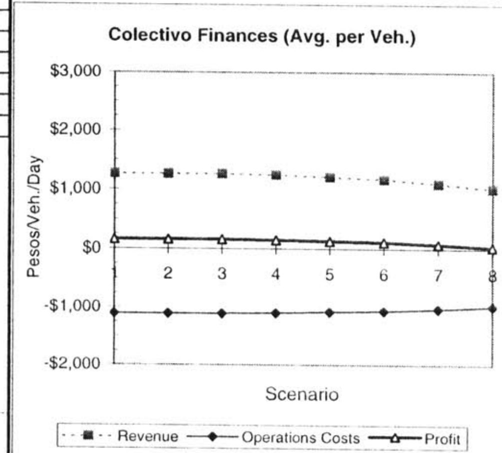
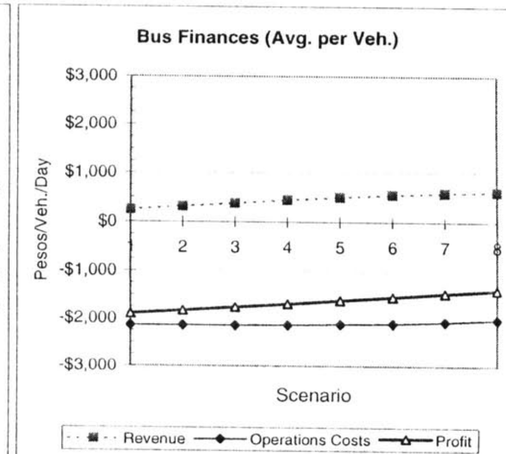
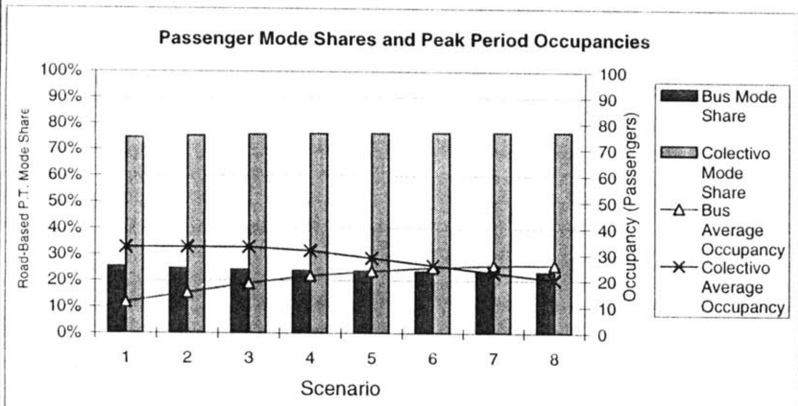
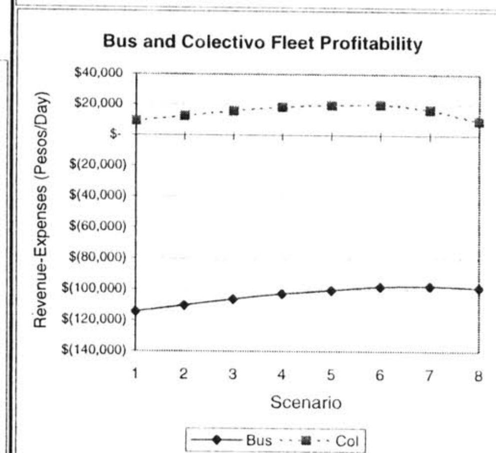
	Auto	Bus	Col	Taxi	Trucks	Total
Observed No. of Veh. (Pk Hr)	817	34	237	182	81	1351
Observed Vehicle Mode Share	60.5%	2.5%	17.5%	13.5%	6.0%	100%
Observed Pass. Mode Share	24.5%	14.1%	58.6%	2.7%	0.0%	100%
Value of Time (Pesos/hr)	$ 15	$ 10	$ 10	$ 15		
Avg. Speed (Kph)	45.6	19.6	29.1	45.6	45.6	
Mixed Lanes	1	1	1	1	1	
Exclusive Lane	0	0	0	0	0	0
Fuel	0	1	0	0	0	0=Gasoline, 1=Diesel

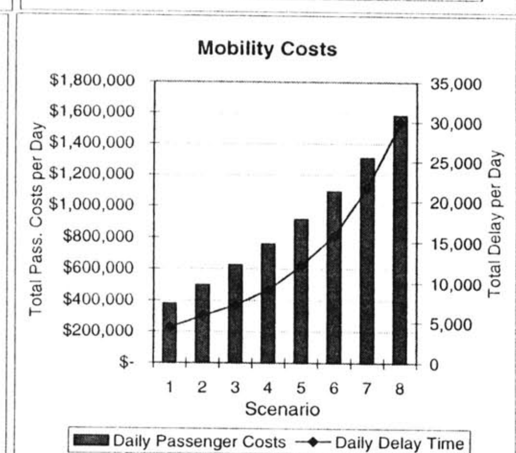
	Trip Km	Fare	Observ.		Distance	
Colectivo	0 - 5	$ 1.50	63.3%	0.950	5	3.165
Fare Structure	5 - 12	$ 2.00	20.4%	0.408	12	2.448
and Avg. Trip	12 - 17	$ 2.50	6.1%	0.153	17	1.037
Length	> 17	$ 2.50	10.2%	0.255	17	1.734
	Total		Avg. Fare	$1.77	Avg. Dist.	8.4











Corridor Test: Varying Demand — 4-lane divided urban arterial (Class II)

		Hourly Peak Demand in One Direction (Pass.-Trips)	Fare ($ Pesos)		Vehicle Capacity		Headway Peak (min.)		Headway Off-Peak (min.)		Colect. Occup.
			Bus	Col	Bus	Col	Bus	Col	Bus	Col	Col
Data:		5000	$1.00	$1.77	70	35	1.76	0.25	2.21	0.32	85%
S	1	3000	$1.00	$1.77	70	35	1.76	1.10	2.21	1.57	85%
C	2	4000	$1.00	$1.77	70	35	1.76	0.81	2.21	1.16	85%
E	3	5000	$1.00	$1.77	70	35	1.76	0.65	2.21	0.92	85%
N	4	6000	$1.00	$1.77	70	35	1.76	0.54	2.21	0.76	85%
A	5	7000	$1.00	$1.77	70	35	1.76	0.46	2.21	0.65	85%
R	6	8000	$1.00	$1.77	70	35	1.76	0.40	2.21	0.57	85%
I	7	9000	$1.00	$1.77	70	35	1.76	0.36	2.21	0.50	85%
O	8	10000	$1.00	$1.77	70	35	1.76	0.32	2.21	0.45	85%

ENVIRONMENTAL RESULTS

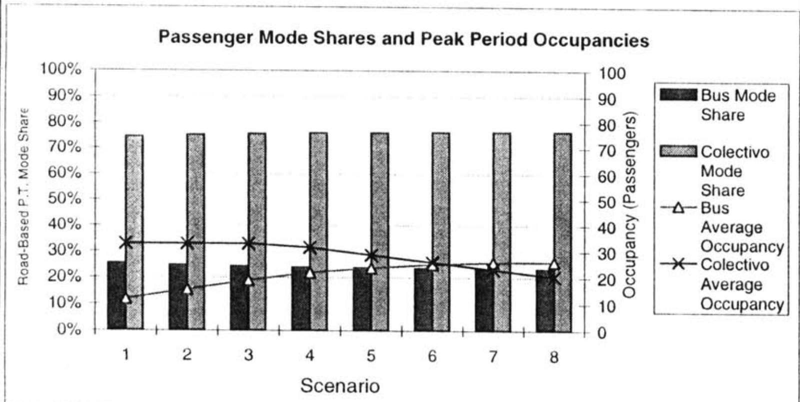
	HC (metric tons)		CO (metric tons)		NOx (metric tons)		PM10 (metric tons)		SO2 (metric tons)		Share of All Emissions		Emissions - All Vehicles	Total Daily Demand
	Bus	Col	Bus	Col	Bus	Col	Bus	Col	Bus	Col	Bus	Col	(m.tons)	(pass.trips)
Data	40.58	163.47	109.33	1794.31	102.65	59.84	7.05	0.95	1.48	3.77	2.8%	21.7%	9,299	72,000
											-4.1%	0.7%	% Δ	
1	43.96	36.59	118.43	403.20	111.20	14.09	7.64	0.22	1.61	0.87	5.7%	9.2%	-47%	43,200
2	43.96	49.42	118.43	544.53	111.20	19.03	7.64	0.30	1.61	1.17	4.5%	9.7%	-32%	57,600
3	43.96	62.24	118.43	685.70	111.20	23.96	7.64	0.37	1.61	1.48	3.6%	10.0%	-16%	72,000
4	43.96	77.34	118.43	848.94	111.20	28.31	7.64	0.45	1.61	1.78	3.0%	10.2%	1%	86,400
5	43.96	90.54	118.43	993.77	111.20	33.14	7.64	0.53	1.61	2.09	2.5%	10.0%	21%	100,800
6	45.84	107.23	126.09	1172.22	114.56	37.21	7.64	0.60	1.61	2.39	2.2%	10.0%	42%	115,200
7	45.84	130.31	126.09	1415.22	114.56	40.46	7.64	0.68	1.61	2.69	1.9%	10.1%	69%	129,600
8	47.86	151.39	134.47	1641.22	118.15	44.53	7.64	0.76	1.61	3.00	1.7%	10.0%	98%	144,000

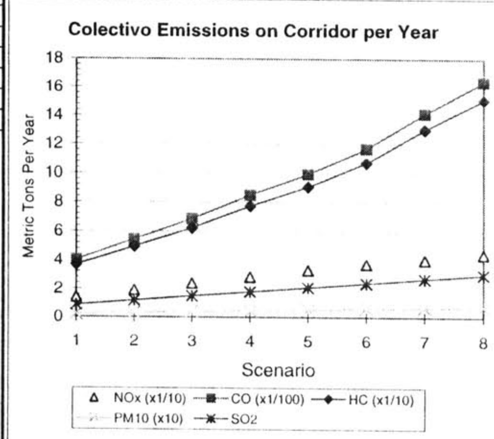
CORRIDOR PARAMETERS:

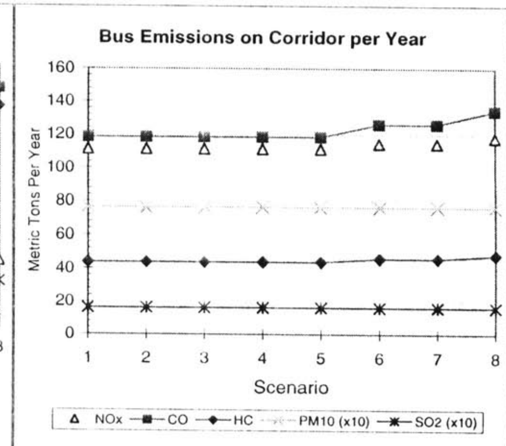
Theoretical Capacity (equiv. veh./hr)	3000	Length, one way (km)	15
Number of Hours in Peak Demand	6	% of Daily Traffic in the Peak Period	42%
Number of Hours in Off-Peak Demand	12	% of Traffic in Peak Direction	55%
% of Hourly Demand during Peak	100%	Avg. Hours of Colectivo Operations/Day	12
% of Hourly Demand during Off-Peak	70%	Number of Colectivo Workdays per Year	320

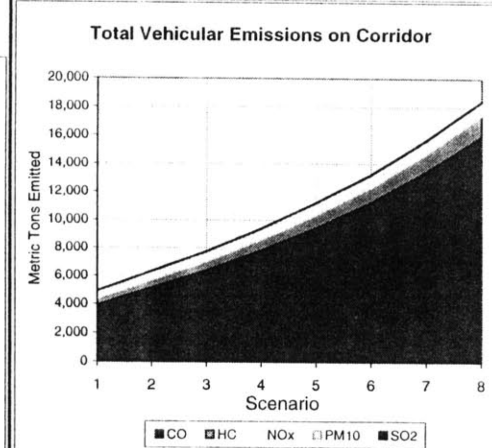
	Auto	Bus	Col	Taxi	Trucks	Total
Observed No. of Veh. (Pk Hr)	817	34	237	182	81	1351
Observed Vehicle Mode Share	60.5%	2.5%	17.5%	13.5%	6.0%	100%
Observed Pass. Mode Share	24.5%	14.1%	58.6%	2.7%	0.0%	100%
Value of Time (Pesos/hr)	$ 15	$ 10	$ 10	$ 15		
Avg. Speed (Kph)	45.6	19.6	29.1	45.6	45.6	
Mixed Lanes	1	1	1	1	1	
Exclusive Lane	0	0	0	0	0	0
Fuel	0	1	0	0	0	0=Gasoline, 1=Diesel

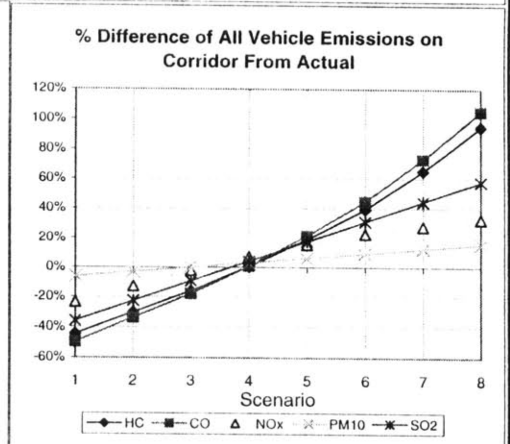
	Trip Km	Fare	Observ.			Distance	
Colectivo	0 - 5	$ 1.50	63.3%	0.950		5	3.165
Fare Structure	5 - 12	$ 2.00	20.4%	0.408		12	2.448
and Avg. Trip	12 - 17	$ 2.50	6.1%	0.153		17	1.037
Length	> 17	$ 2.50	10.2%	0.255		17	1.734
	Total	Avg. Fare		$1.77		Avg. Dist.	8.4











Corridor Test: Varying Bus Fare — 4-lane divided urban arterial (Class II)

	Hourly Peak Demand in One Direction (Pass.-Trips)	Fare ($ Pesos) Bus	Fare ($ Pesos) Col	Vehicle Capacity Bus	Vehicle Capacity Col	Headway Peak (min.) Bus	Headway Peak (min.) Col	Headway Off-Peak (min.) Bus	Headway Off-Peak (min.) Col	Colect. Occup. Col
Data:	5000	$1.00	$1.77	70	35	1.76	0.25	2.21	0.32	85%
SCENARIO 1	5000	$0.00	$1.77	70	35	1.76	1.29	2.21	1.86	85%
2	5000	$0.50	$1.77	70	35	1.76	0.85	2.21	1.21	85%
3	5000	$1.00	$1.77	70	35	1.76	0.65	2.21	0.92	85%
4	5000	$1.50	$1.77	70	35	1.76	0.55	2.21	0.78	85%
5	5000	$2.00	$1.77	70	35	1.76	0.50	2.21	0.71	85%
6	5000	$2.50	$1.77	70	35	1.76	0.49	2.21	0.71	85%
7	5000	$3.00	$1.77	70	35	1.76	0.49	2.21	0.71	85%
8	5000	$3.50	$1.77	70	35	1.76	0.49	2.21	0.71	85%

OPERATIONAL RESULTS

	Pk-Hr Pass. Mode Share (of R.B.P.T. Trips) Bus	Pk-Hr Pass. Mode Share Col	Passengers Per Day Bus	Passengers Per Day Col	Corridor LOS Peak	Corridor LOS Off-Pk	VKT per Year on Corridor Bus	VKT per Year on Corridor Col	Daily VKT per Vehicle Bus	Daily VKT per Vehicle Col	No. of Veh. Operating in Peak Bus	No. of Veh. Operating in Peak Col	No. of Veh. Operating in Off-Pk Bus	No. of Veh. Operating in Off-Pk Col
Data:	19.4%	80.6%	10163	42224	B	A	4,700,160	32,762,880	236	337	53	258	36	175
SCENARIO 1	61.9%	38.1%	32428	19959	A	A	5,091,238	6,405,214	264	397	46	42	37	29
2	42.2%	57.8%	22099	30288	A	A	5,091,238	9,801,315	264	397	46	64	37	45
3	24.2%	75.8%	12693	39695	A	A	5,091,238	12,855,820	264	397	46	84	37	59
4	10.1%	89.9%	5281	47106	A	A	5,091,238	15,241,310	264	397	46	100	37	70
5	1.9%	98.1%	1013	51374	A	A	5,091,238	16,594,339	264	397	46	109	37	76
6	0.8%	99.2%	419	51968	A	A	5,091,238	16,769,539	264	397	46	110	37	77
7	0.8%	99.2%	419	51968	A	A	5,091,238	16,769,539	264	397	46	110	37	77
8	0.8%	99.2%	419	51968	A	A	5,091,238	16,769,539	264	397	46	110	37	77

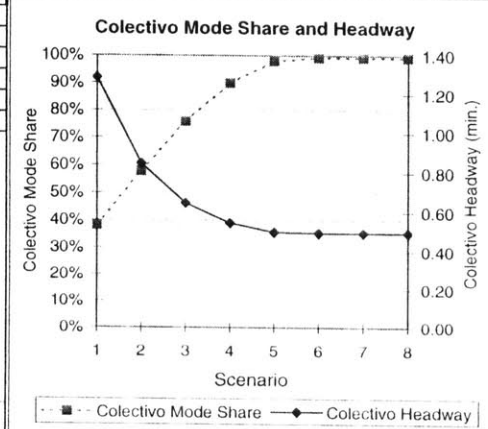
CORRIDOR PARAMETERS:

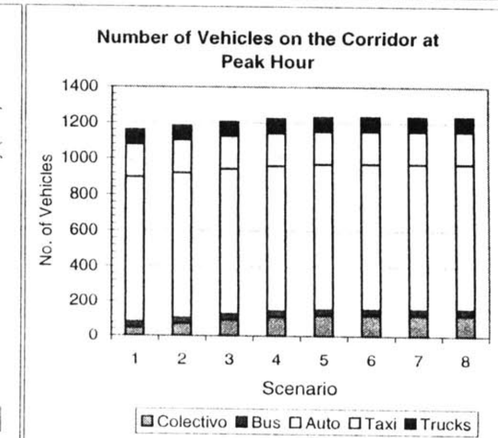
Theoretical Capacity (equiv. veh./hr)	3000	Length, one way (km)	15
Number of Hours in Peak Demand	6	% of Daily Traffic in the Peak Period	42%
Number of Hours in Off-Peak Demand	12	% of Traffic in Peak Direction	55%
% of Hourly Demand during Peak	100%	Avg. Hours of Colectivo Operations/Day	12
% of Hourly Demand during Off-Peak	70%	Number of Colectivo Workdays per Year	320

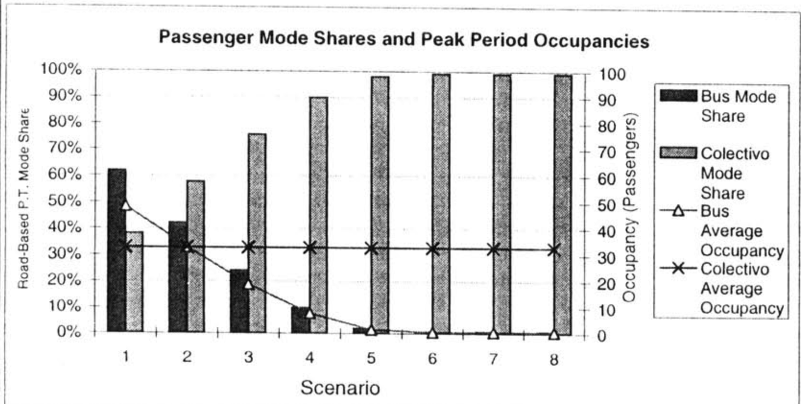
	Auto	Bus	Col	Taxi	Trucks	Total
Observed No. of Veh. (Pk Hr)	817	34	237	182	81	1351
Observed Vehicle Mode Share	60.5%	2.5%	17.5%	13.5%	6.0%	100%
Observed Pass. Mode Share	24.5%	14.1%	58.6%	2.7%	0.0%	100%
Value of Time (Pesos/hr)	$ 15	$ 10	$ 10	$ 15		
Avg. Speed (Kph)	45.6	19.6	29.1	45.6	45.6	
Mixed Lanes	1	1	1	1	1	
Exclusive Lane	0	0	0	0	0	0
Fuel	0	1	0	0	0	0=Gasoline, 1=Diesel

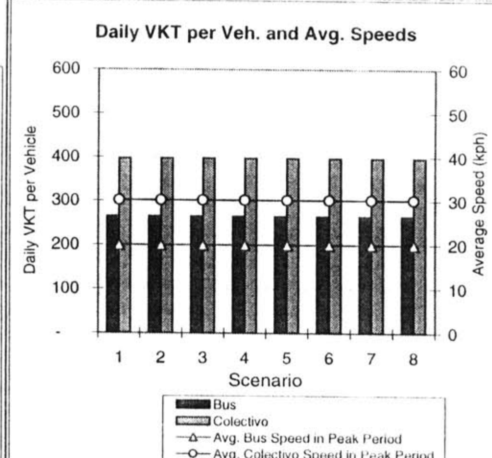
Colectivo Fare Structure and Avg. Trip Length	Trip Km	Fare	Observ.	
	0 - 5	$ 1.50	63.3%	0.950
	5 - 12	$ 2.00	20.4%	0.408
	12 - 17	$ 2.50	6.1%	0.153
	> 17	$ 2.50	10.2%	0.255
	Total		Avg. Fare	$1.77

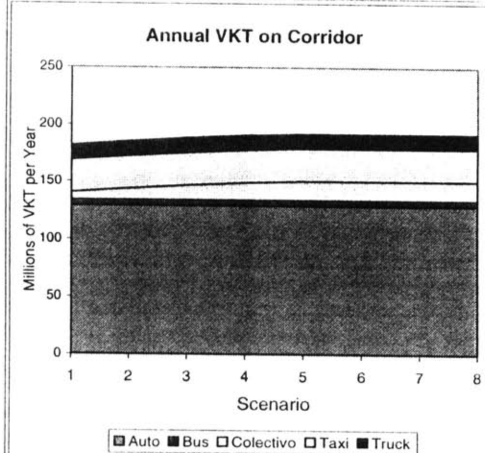
Distance	
5	3.165
12	2.448
17	1.037
17	1.734
Avg. Dist.	8.4











Corridor Test:	Varying Bus Fare	4-lane divided urban arterial (Class II)

		Hourly Peak Demand in One Direction (Pass.-Trips)	Fare ($ Pesos)		Vehicle Capacity		Headway Peak (min.)		Headway Off-Peak (min.)		Colect. Occup.
			Bus	Col	Bus	Col	Bus	Col	Bus	Col	Col
Data:		5000	$1.00	$1.77	70	35	1.76	0.25	2.21	0.32	85%
S	1	5000	$0.00	$1.77	70	35	1.76	1.29	2.21	1.86	85%
C	2	5000	$0.50	$1.77	70	35	1.76	0.85	2.21	1.21	85%
E	3	5000	$1.00	$1.77	70	35	1.76	0.65	2.21	0.92	85%
N	4	5000	$1.50	$1.77	70	35	1.76	0.55	2.21	0.78	85%
A	5	5000	$2.00	$1.77	70	35	1.76	0.50	2.21	0.71	85%
R	6	5000	$2.50	$1.77	70	35	1.76	0.49	2.21	0.71	85%
I	7	5000	$3.00	$1.77	70	35	1.76	0.49	2.21	0.71	85%
O	8	5000	$3.50	$1.77	70	35	1.76	0.49	2.21	0.71	85%

ECONOMIC RESULTS

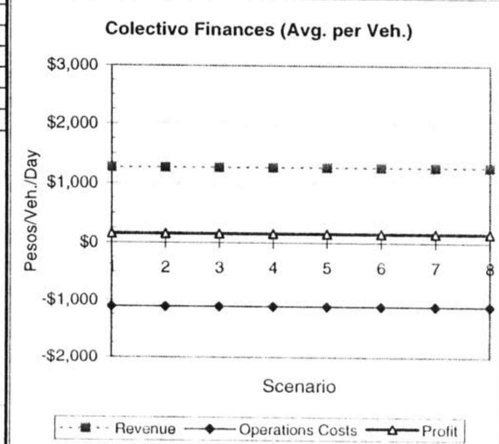
	Total Daily Costs (All Modes & Both Dir.)	Daily Delay in Pk. Dir. (hrs.)	Operational Cost per Veh. Per Day		Revenue per Veh. Per Day		Fleet Profitability per Day		Profit Per Vehicle Per Day		Profit/Loss Margin	
			Bus	Col	Bus	Col	Bus	Col	Bus	Col	Bus	Col
Data	$ 682,086	12,787	$ (2,054)	$ (1,008)	$ 297	$ 446	$ (109,298)	$ (170,580)	$ (1,757)	$ (562)	-85.5%	-55.7%
	-12.9%	-45.1%					-2%	162%	-2%	0%		
1	$ 594,417	10,019	$ (2,141)	$ (1,106)	$ -	$ 1,264	$ (129,039)	$ 7,949	$ (2,141)	$ 158	######	14.3%
2	$ 618,162	8,540	$ (2,141)	$ (1,106)	$ 332	$ 1,264	$ (109,027)	$ 12,163	$ (1,809)	$ 158	-84.5%	14.3%
3	$ 624,325	7,209	$ (2,141)	$ (1,106)	$ 379	$ 1,264	$ (106,225)	$ 15,954	$ (1,763)	$ 158	-82.3%	14.3%
4	$ 618,197	6,169	$ (2,141)	$ (1,106)	$ 233	$ 1,264	$ (114,980)	$ 18,914	$ (1,908)	$ 158	-89.1%	14.3%
5	$ 609,128	5,580	$ (2,141)	$ (1,106)	$ 58	$ 1,264	$ (125,540)	$ 20,593	$ (2,083)	$ 158	-97.3%	14.3%
6	$ 607,729	5,503	$ (2,141)	$ (1,106)	$ 32	$ 1,264	$ (127,134)	$ 20,811	$ (2,110)	$ 158	-98.5%	14.3%
7	$ 608,110	5,503	$ (2,141)	$ (1,106)	$ 38	$ 1,264	$ (126,753)	$ 20,811	$ (2,103)	$ 158	-98.2%	14.3%
8	$ 608,491	5,503	$ (2,141)	$ (1,106)	$ 44	$ 1,264	$ (126,372)	$ 20,811	$ (2,097)	$ 158	-97.9%	14.3%

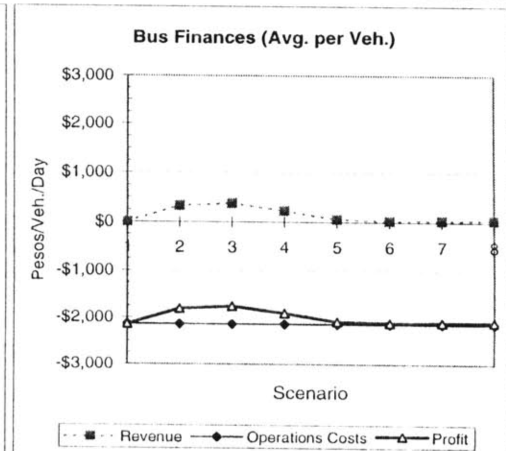
CORRIDOR PARAMETERS:

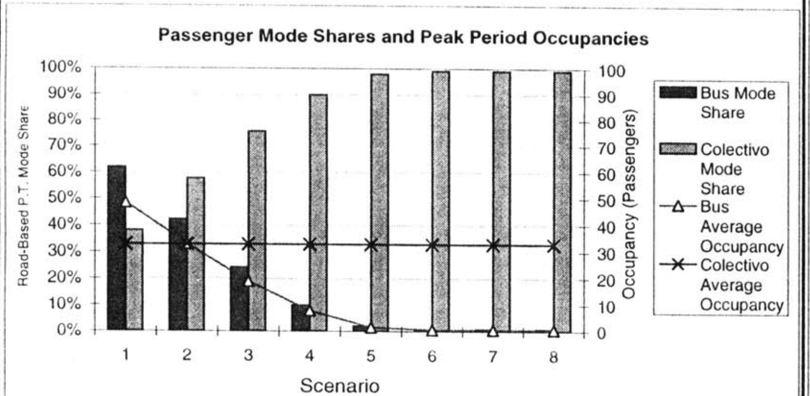
Theoretical Capacity (equiv. veh./hr)	3000	Length, one way (km)	15
Number of Hours in Peak Demand	6	% of Daily Traffic in the Peak Period	42%
Number of Hours in Off-Peak Demand	12	% of Traffic in Peak Direction	55%
% of Hourly Demand during Peak	100%	Avg. Hours of Colectivo Operations/Day	12
% of Hourly Demand during Off-Peak	70%	Number of Colectivo Workdays per Year	320

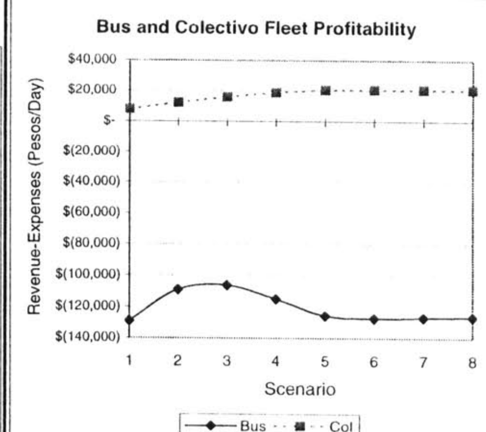
	Auto	Bus	Col	Taxi	Trucks	Total
Observed No. of Veh. (Pk Hr)	817	34	237	182	81	1351
Observed Vehicle Mode Share	60.5%	2.5%	17.5%	13.5%	6.0%	100%
Observed Pass. Mode Share	24.5%	14.1%	58.6%	2.7%	0.0%	100%
Value of Time (Pesos/hr)	$ 15	$ 10	$ 10	$ 15		
Avg. Speed (Kph)	45.6	19.6	29.1	45.6	45.6	
Mixed Lanes	1	1	1	1	1	
Exclusive Lane	0	0	0	0	0	0
Fuel	0	1	0	0	0	0=Gasoline, 1=Diesel

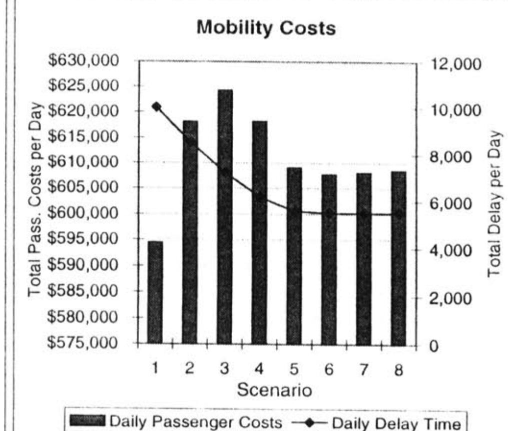
	Trip Km	Fare	Observ.			Distance	
Colectivo	0 - 5	$ 1.50	63.3%	0.950		5	3.165
Fare Structure	5 - 12	$ 2.00	20.4%	0.408		12	2.448
and Avg. Trip	12 - 17	$ 2.50	6.1%	0.153		17	1.037
Length	> 17	$ 2.50	10.2%	0.255		17	1.734
	Total		Avg. Fare	$1.77		Avg. Dist.	8.4











Corridor Test: Varying Bus Fare — 4-lane divided urban arterial (Class II)

	Hourly Peak Demand in One Direction (Pass.-Trips)	Fare ($ Pesos) Bus	Fare ($ Pesos) Col	Vehicle Capacity Bus	Vehicle Capacity Col	Headway Peak (min.) Bus	Headway Peak (min.) Col	Headway Off-Peak (min.) Bus	Headway Off-Peak (min.) Col	Colect. Occup. Col
Data:	5000	$1.00	$1.77	70	35	1.76	0.25	2.21	0.32	85%
SCENARIO 1	5000	$0.00	$1.77	70	35	1.76	1.29	2.21	1.86	85%
2	5000	$0.50	$1.77	70	35	1.76	0.85	2.21	1.21	85%
3	5000	$1.00	$1.77	70	35	1.76	0.65	2.21	0.92	85%
4	5000	$1.50	$1.77	70	35	1.76	0.55	2.21	0.78	85%
5	5000	$2.00	$1.77	70	35	1.76	0.50	2.21	0.71	85%
6	5000	$2.50	$1.77	70	35	1.76	0.49	2.21	0.71	85%
7	5000	$3.00	$1.77	70	35	1.76	0.49	2.21	0.71	85%
8	5000	$3.50	$1.77	70	35	1.76	0.49	2.21	0.71	85%

ENVIRONMENTAL RESULTS

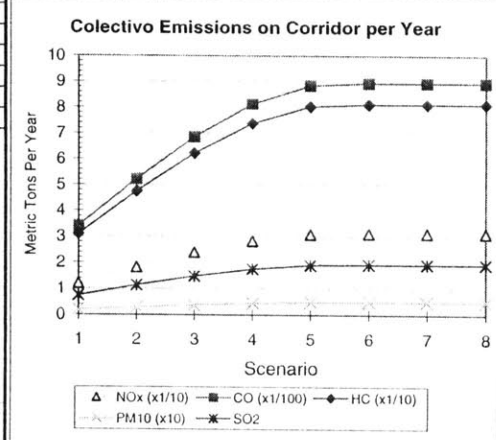
	HC (metric tons) Bus	HC (metric tons) Col	CO (metric tons) Bus	CO (metric tons) Col	NOx (metric tons) Bus	NOx (metric tons) Col	PM10 (metric tons) Bus	PM10 (metric tons) Col	SO2 (metric tons) Bus	SO2 (metric tons) Col	Share of All Emissions Bus	Share of All Emissions Col	Emissions - All Vehicles (m.tons)	Total Daily Demand (pass.trips)
Data	40.58	163.47	109.33	1794.31	102.65	59.84	7.05	0.95	1.48	3.77	2.8%	21.7%	9,299	72,000
											-0.3%	7.4%	% Δ	
1	43.96	31.01	118.43	341.64	111.20	11.94	7.64	0.19	1.61	0.74	3.8%	5.2%	-21%	72,000
2	43.96	47.45	118.43	522.78	111.20	18.27	7.64	0.28	1.61	1.13	3.7%	7.8%	-18%	72,000
3	43.96	62.24	118.43	685.70	111.20	23.96	7.64	0.37	1.61	1.48	3.6%	10.0%	-16%	72,000
4	43.96	73.78	118.43	812.94	111.20	28.41	7.64	0.44	1.61	1.75	3.6%	11.6%	-15%	72,000
5	43.96	80.33	118.43	885.11	111.20	30.93	7.64	0.48	1.61	1.91	3.5%	12.5%	-14%	72,000
6	43.96	81.18	118.43	894.45	111.20	31.26	7.64	0.49	1.61	1.93	3.5%	12.6%	-14%	72,000
7	43.96	81.18	118.43	894.45	111.20	31.26	7.64	0.49	1.61	1.93	3.5%	12.6%	-14%	72,000
8	43.96	81.18	118.43	894.45	111.20	31.26	7.64	0.49	1.61	1.93	3.5%	12.6%	-14%	72,000

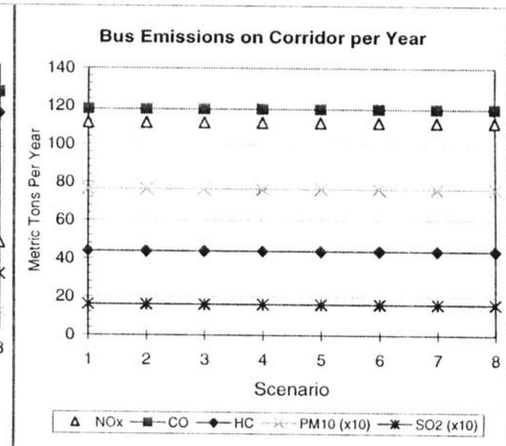
CORRIDOR PARAMETERS:

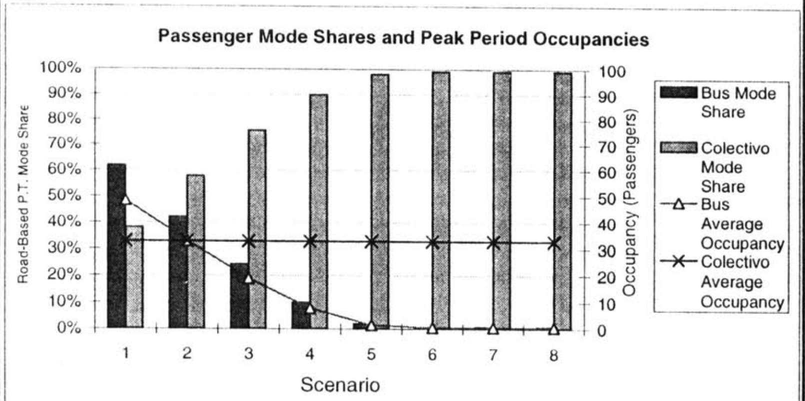
Theoretical Capacity (equiv. veh./hr)	3000	Length, one way (km)	15
Number of Hours in Peak Demand	6	% of Daily Traffic in the Peak Period	42%
Number of Hours in Off-Peak Demand	12	% of Traffic in Peak Direction	55%
% of Hourly Demand during Peak	100%	Avg. Hours of Colectivo Operations/Day	12
% of Hourly Demand during Off-Peak	70%	Number of Colectivo Workdays per Year	320

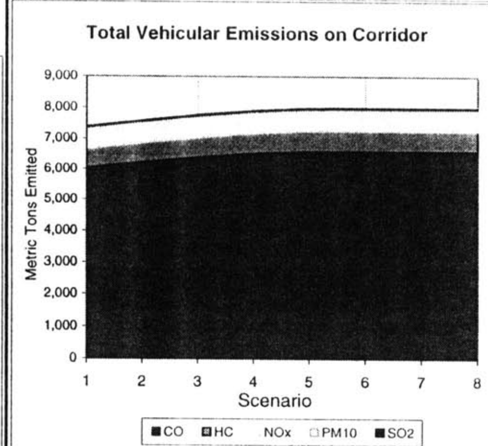
	Auto	Bus	Col	Taxi	Trucks	Total
Observed No. of Veh. (Pk Hr)	817	34	237	182	81	1351
Observed Vehicle Mode Share	60.5%	2.5%	17.5%	13.5%	6.0%	100%
Observed Pass. Mode Share	24.5%	14.1%	58.6%	2.7%	0.0%	100%
Value of Time (Pesos/hr)	$ 15	$ 10	$ 10	$ 15		
Avg. Speed (Kph)	45.6	19.6	29.1	45.6	45.6	
Mixed Lanes	1	1	1	1	1	
Exclusive Lane	0	0	0	0	0	0
Fuel	0	1	0	0	0	0=Gasoline, 1=Diesel

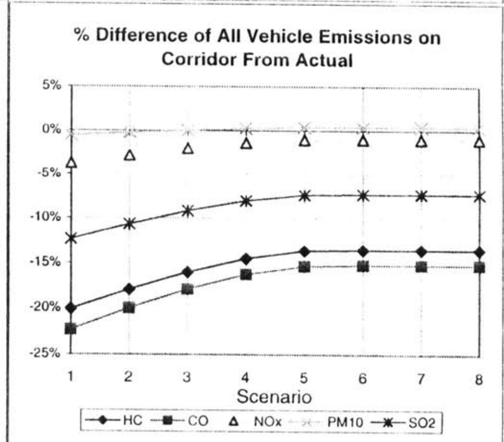
	Trip Km	Fare	Observ.		Distance	
Colectivo	0 - 5	$ 1.50	63.3%	0.950	5	3.165
Fare Structure	5 - 12	$ 2.00	20.4%	0.408	12	2.448
and Avg. Trip	12 - 17	$ 2.50	6.1%	0.153	17	1.037
Length	> 17	$ 2.50	10.2%	0.255	17	1.734
	Total		Avg. Fare	$1.77	Avg. Dist.	8.4











Corridor Test:	Varying Colectivo Size	4-lane divided urban arterial (Class II)

	Hourly Peak Demand in One Direction (Pass.-Trips)	Fare ($ Pesos)		Vehicle Capacity		Headway Peak (min.)		Headway Off-Peak (min.)		Colect. Occup.
		Bus	Col	Bus	Col	Bus	Col	Bus	Col	Col
Data:	5000	$1.00	$1.77	70	35	1.76	0.25	2.21	0.32	85%
SCENARIO 1	5000	$1.00	$1.77	70	15	1.76	0.23	2.21	0.32	85%
2	5000	$1.00	$1.77	70	25	1.76	0.41	2.21	0.58	85%
3	5000	$1.00	$1.77	70	35	1.76	0.65	2.21	0.92	85%
4	5000	$1.00	$1.77	70	45	1.76	0.97	2.21	1.39	85%
5	5000	$1.00	$1.77	70	55	1.76	1.47	2.21	2.13	85%
6	5000	$1.00	$1.77	70	60	1.76	1.83	2.21	2.70	85%
7	5000	$1.00	$1.77	70	65	1.76	2.34	2.21	3.56	85%
8	5000	$1.00	$1.77	70	70	1.76	3.14	2.21	5.30	85%

OPERATIONAL RESULTS

	Pk-Hr Pass. Mode Share (of R.B.P.T. Trips)		Passengers Per Day		Corridor LOS		VKT per Year on Corridor		Daily VKT per Vehicle		No. of Veh. Operating in Peak		No. of Veh. Operating in Off-Pk	
	Bus	Col	Bus	Col	Peak	Off-Pk	Bus	Col	Bus	Col	Bus	Col	Bus	Col
Data	19.4%	80.6%	10163	42224	B	A	4,700,160	32,762,880	236	337	53	258	36	175
1	7.5%	92.5%	3936	48452	B	A	5,091,238	36,613,613	263	500	47	193	37	133
2	14.9%	85.1%	7781	44606	A	A	5,091,238	20,236,713	264	445	46	118	37	83
3	24.2%	75.8%	12693	39695	A	A	5,091,238	12,855,820	264	397	46	84	37	59
4	35.2%	64.8%	18457	33931	A	A	5,091,238	8,523,779	264	359	46	62	37	43
5	47.5%	52.5%	24907	27480	A	A	5,091,238	5,603,150	264	327	46	45	37	31
6	54.2%	45.8%	28372	24015	A	A	5,091,238	4,448,071	264	314	46	38	37	26
7	61.1%	38.9%	32029	20358	A	A	5,091,238	3,415,705	264	301	46	31	37	20
8	68.7%	31.3%	36006	16381	A	A	5,091,238	2,406,456	264	289	46	24	37	14

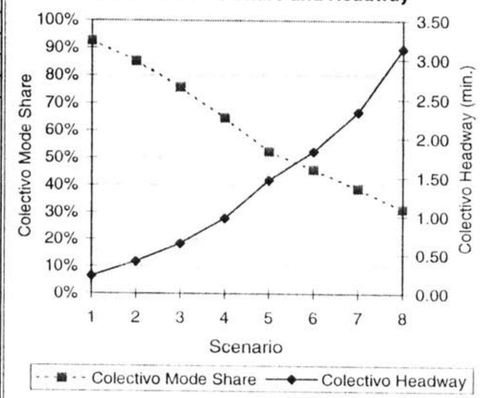
CORRIDOR PARAMETERS:

Theoretical Capacity (equiv. veh./hr)	3000	Length, one way (km)	15
Number of Hours in Peak Demand	6	% of Daily Traffic in the Peak Period	42%
Number of Hours in Off-Peak Demand	12	% of Traffic in Peak Direction	55%
% of Hourly Demand during Peak	100%	Avg. Hours of Colectivo Operations/Day	12
% of Hourly Demand during Off-Peak	70%	Number of Colectivo Workdays per Year	320

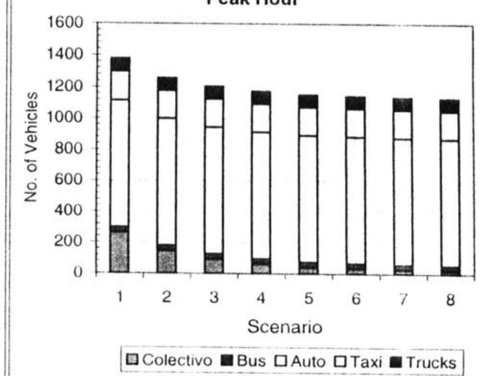
	Auto	Bus	Col	Taxi	Trucks	Total
Observed No. of Veh. (Pk Hr)	817	34	237	182	81	1351
Observed Vehicle Mode Share	60.5%	2.5%	17.5%	13.5%	6.0%	100%
Observed Pass. Mode Share	24.5%	14.1%	58.6%	2.7%	0.0%	100%
Value of Time (Pesos/hr)	$ 15	$ 10	$ 10	$ 15		
Avg. Speed (Kph)	45.6	19.6	29.1	45.6	45.6	
Mixed Lanes	1	1	1	1	1	
Exclusive Lane	0	0	0	0	0	0
Fuel	0	1	0	0	0	0=Gasoline, 1=Diesel

	Trip Km	Fare	Observ.		Distance	
Colectivo Fare Structure and Avg. Trip Length	0 - 5	$ 1.50	63.3%	0.950	5	3.165
	5 - 12	$ 2.00	20.4%	0.408	12	2.448
	12 - 17	$ 2.50	6.1%	0.153	17	1.037
	> 17	$ 2.50	10.2%	0.255	17	1.734
	Total		**Avg. Fare**	**$1.77**	**Avg. Dist.**	**8.4**

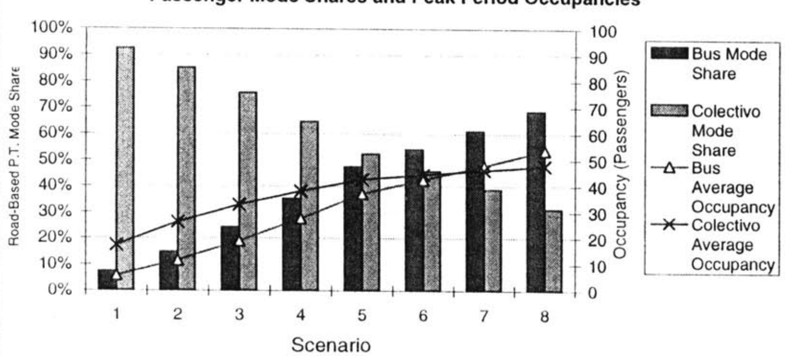
Colectivo Mode Share and Headway



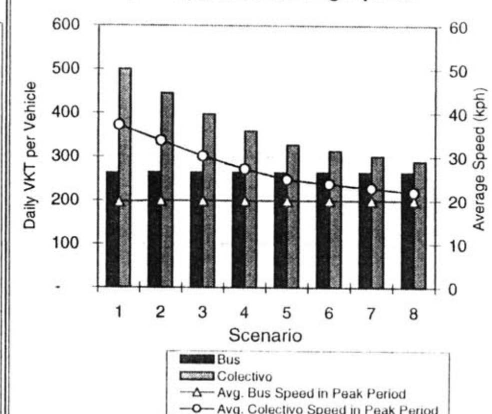
Number of Vehicles on the Corridor at Peak Hour



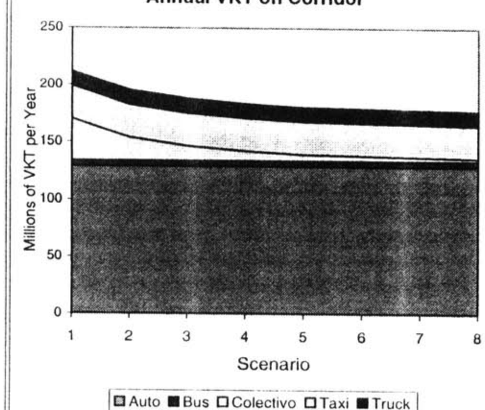
Passenger Mode Shares and Peak Period Occupancies



Daily VKT per Veh. and Avg. Speeds



Annual VKT on Corridor



Corridor Test: Varying Colectivo Size — 4-lane divided urban arterial (Class II)

		Hourly Peak Demand in One Direction (Pass.-Trips)	Fare ($ Pesos)		Vehicle Capacity		Headway Peak (min.)		Headway Off-Peak (min.)		Colect. Occup.
			Bus	Col	Bus	Col	Bus	Col	Bus	Col	Col
Data:		5000	$1.00	$1.77	70	35	1.76	0.25	2.21	0.32	85%
S	1	5000	$1.00	$1.77	70	15	1.76	0.23	2.21	0.32	85%
C	2	5000	$1.00	$1.77	70	25	1.76	0.41	2.21	0.58	85%
E	3	5000	$1.00	$1.77	70	35	1.76	0.65	2.21	0.92	85%
N	4	5000	$1.00	$1.77	70	45	1.76	0.97	2.21	1.39	85%
A	5	5000	$1.00	$1.77	70	55	1.76	1.47	2.21	2.13	85%
R	6	5000	$1.00	$1.77	70	60	1.76	1.83	2.21	2.70	85%
I	7	5000	$1.00	$1.77	70	65	1.76	2.34	2.21	3.56	85%
O	8	5000	$1.00	$1.77	70	70	1.76	3.14	2.21	5.30	85%

ECONOMIC RESULTS

Scenario	Total Daily Costs (All Modes & Both Dir.)	Daily Delay in Pk. Dir. (hrs.)	Operational Cost per Veh. Per Day		Revenue per Veh. Per Day		Fleet Profitability per Day		Profit Per Vehicle Per Day		Profit/Loss Margin	
			Bus	Col	Bus	Col	Bus	Col	Bus	Col	Bus	Col
Data	$ 682,086	12,787	$ (2,054)	$ (1,008)	$ 297	$ 446	$ (109,298)	$ (170,580)	$ (1,757)	$ (562)	-85.5%	-55.7%
	-17.7%	270.6%					-50%	-80%	-50%	79%		
1	$ 561,071	3,309	$ (2,137)	$ (778)	$ 113	$ 682	$ (122,586)	$ (21,789)	$ (2,024)	$ (95)	-94.7%	-12.3%
2	$ 591,500	5,182	$ (2,141)	$ (892)	$ 229	$ 1,011	$ (115,234)	$ 16,917	$ (1,912)	$ 119	-89.3%	13.3%
3	$ 624,325	7,209	$ (2,141)	$ (1,106)	$ 379	$ 1,264	$ (106,225)	$ 15,954	$ (1,763)	$ 158	-82.3%	14.3%
4	$ 652,653	9,044	$ (2,141)	$ (1,326)	$ 556	$ 1,469	$ (95,538)	$ 10,612	$ (1,585)	$ 143	-74.0%	10.8%
5	$ 674,944	10,594	$ (2,141)	$ (1,567)	$ 757	$ 1,637	$ (83,401)	$ 3,767	$ (1,384)	$ 70	-64.6%	4.5%
6	$ 683,424	11,242	$ (2,141)	$ (1,702)	$ 868	$ 1,711	$ (76,754)	$ 423	$ (1,274)	$ 10	-59.5%	0.6%
7	$ 689,885	11,798	$ (2,141)	$ (1,849)	$ 987	$ 1,779	$ (69,531)	$ (2,485)	$ (1,154)	$ (70)	-53.9%	-3.8%
8	$ 693,885	12,263	$ (2,141)	$ (2,012)	$1,131	$ 1,841	$ (60,908)	$ (4,435)	$ (1,011)	$ (171)	-47.2%	-8.5%

CORRIDOR PARAMETERS:

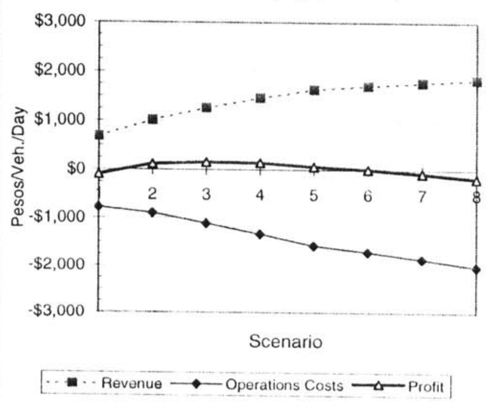
Theoretical Capacity (equiv. veh./hr)	3000	Length, one way (km)	15
Number of Hours in Peak Demand	6	% of Daily Traffic in the Peak Period	42%
Number of Hours in Off-Peak Demand	12	% of Traffic in Peak Direction	55%
% of Hourly Demand during Peak	100%	Avg. Hours of Colectivo Operations/Day	12
% of Hourly Demand during Off-Peak	70%	Number of Colectivo Workdays per Year	320

	Auto	Bus	Col	Taxi	Trucks	Total
Observed No. of Veh. (Pk Hr)	817	34	237	182	81	1351
Observed Vehicle Mode Share	60.5%	2.5%	17.5%	13.5%	6.0%	100%
Observed Pass. Mode Share	24.5%	14.1%	58.6%	2.7%	0.0%	100%
Value of Time (Pesos/hr)	$ 15	$ 10	$ 10	$ 15		
Avg. Speed (Kph)	45.6	19.6	29.1	45.6	45.6	
Mixed Lanes	1	1	1	1	1	
Exclusive Lane	0	0	0	0	0	0
Fuel	0	1	0	0	0	0=Gasoline, 1=Diesel

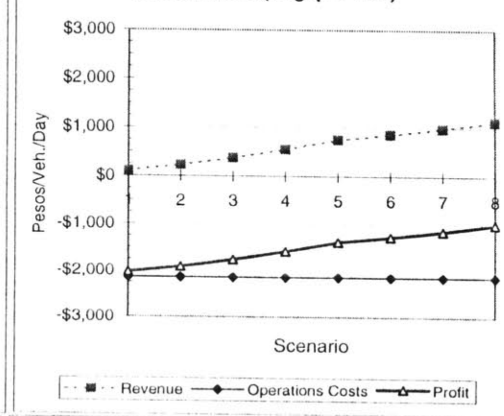
Colectivo Fare Structure and Avg. Trip Length	Trip Km	Fare	Observ.	
	0 - 5	$ 1.50	63.3%	0.950
	5 - 12	$ 2.00	20.4%	0.408
	12 - 17	$ 2.50	6.1%	0.153
	> 17	$ 2.50	10.2%	0.255
	Total		Avg. Fare	$1.77

Distance	
5	3.165
12	2.448
17	1.037
17	1.734
Avg. Dist.	8.4

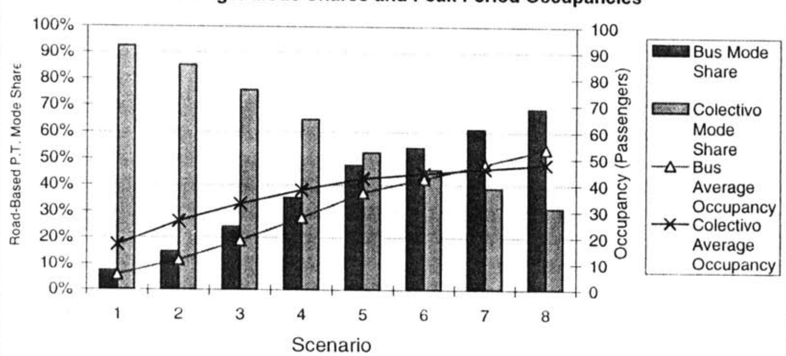
Colectivo Finances (Avg. per Veh.)



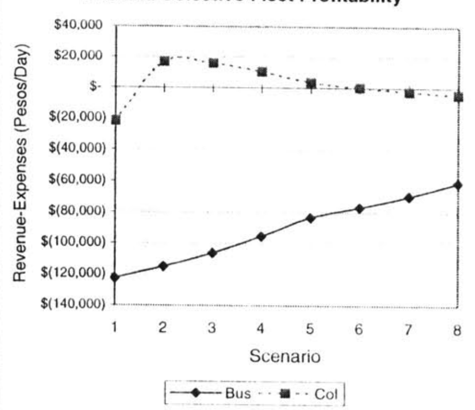
Bus Finances (Avg. per Veh.)



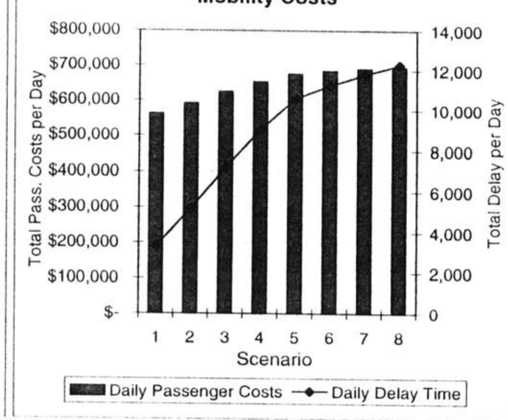
Passenger Mode Shares and Peak Period Occupancies



Bus and Colectivo Fleet Profitability



Mobility Costs



Corridor Test:	Varying Colectivo Size	4-lane divided urban arterial (Class II)

	Hourly Peak Demand in One Direction (Pass.-Trips)	Fare ($ Pesos)		Vehicle Capacity		Headway Peak (min.)		Headway Off-Peak (min.)		Colect. Occup.
		Bus	Col	Bus	Col	Bus	Col	Bus	Col	Col
Data:	5000	$1.00	$1.77	70	35	1.76	0.25	2.21	0.32	85%
SCENARIO 1	5000	$1.00	$1.77	70	15	1.76	0.23	2.21	0.32	85%
2	5000	$1.00	$1.77	70	25	1.76	0.41	2.21	0.58	85%
3	5000	$1.00	$1.77	70	35	1.76	0.65	2.21	0.92	85%
4	5000	$1.00	$1.77	70	45	1.76	0.97	2.21	1.39	85%
5	5000	$1.00	$1.77	70	55	1.76	1.47	2.21	2.13	85%
6	5000	$1.00	$1.77	70	60	1.76	1.83	2.21	2.70	85%
7	5000	$1.00	$1.77	70	65	1.76	2.34	2.21	3.56	85%
8	5000	$1.00	$1.77	70	70	1.76	3.14	2.21	5.30	85%

ENVIRONMENTAL RESULTS

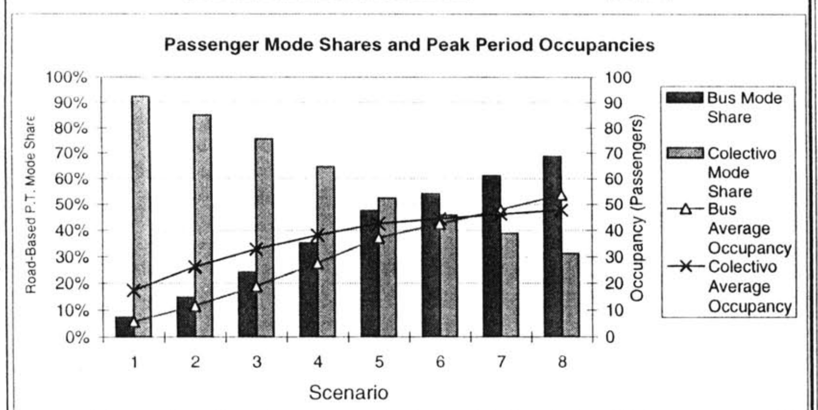
	HC (metric tons)		CO (metric tons)		NOx (metric tons)		PM10 (metric tons)		SO2 (metric tons)		Share of All Emissions		Emissions - All Vehicles	Total Daily Demand
	Bus	Col	Bus	Col	Bus	Col	Bus	Col	Bus	Col	Bus	Col	(m.tons)	(pass.trips)
Data	40.58	163.47	109.33	1794.31	102.65	59.84	7.05	0.95	1.48	3.77	2.8%	21.7%	9,299	72,000
											0.9%	-19.3%	% Δ	
1	43.96	157.57	118.43	1753.17	111.20	77.71	7.64	1.06	1.61	4.21	3.1%	21.8%	-2%	72,000
2	43.96	92.87	118.43	1030.62	111.20	39.61	7.64	0.59	1.61	2.33	3.5%	14.3%	-12%	72,000
3	43.96	62.24	118.43	685.70	111.20	23.96	7.64	0.37	1.61	1.48	3.6%	10.0%	-16%	72,000
4	43.96	43.97	118.43	480.61	111.20	15.26	7.64	0.25	1.61	0.98	3.8%	7.2%	-19%	72,000
5	43.96	31.16	118.43	338.39	111.20	9.67	7.64	0.16	1.61	0.64	3.8%	5.2%	-21%	72,000
6	43.96	24.74	118.43	268.63	111.20	7.68	7.64	0.13	1.61	0.51	3.9%	4.1%	-22%	72,000
7	43.96	19.83	118.43	214.98	111.20	5.83	7.64	0.10	1.61	0.39	3.9%	3.3%	-22%	72,000
8	43.96	14.65	118.43	158.79	111.20	4.07	7.64	0.07	1.61	0.28	3.9%	2.5%	-23%	72,000

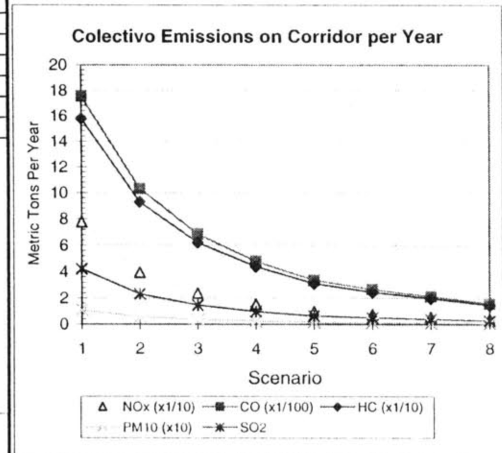
CORRIDOR PARAMETERS:

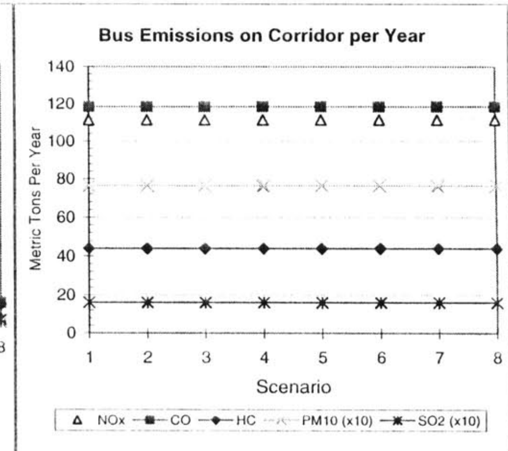
Theoretical Capacity (equiv. veh./hr)	3000	Length, one way (km)	15
Number of Hours in Peak Demand	6	% of Daily Traffic in the Peak Period	42%
Number of Hours in Off-Peak Demand	12	% of Traffic in Peak Direction	55%
% of Hourly Demand during Peak	100%	Avg. Hours of Colectivo Operations/Day	12
% of Hourly Demand during Off-Peak	70%	Number of Colectivo Workdays per Year	320

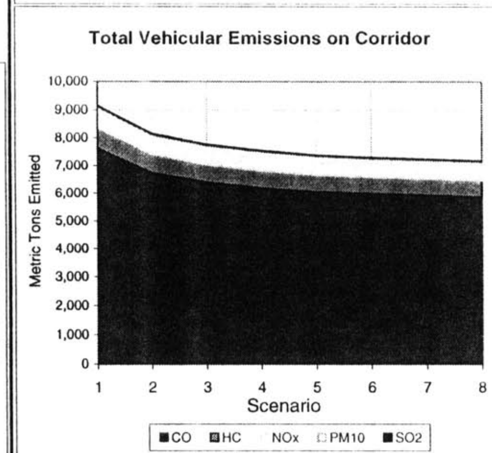
	Auto	Bus	Col	Taxi	Trucks	Total
Observed No. of Veh. (Pk Hr)	817	34	237	182	81	1351
Observed Vehicle Mode Share	60.5%	2.5%	17.5%	13.5%	6.0%	100%
Observed Pass. Mode Share	24.5%	14.1%	58.6%	2.7%	0.0%	100%
Value of Time (Pesos/hr)	$ 15	$ 10	$ 10	$ 15		
Avg. Speed (Kph)	45.6	19.6	29.1	45.6	45.6	
Mixed Lanes	1	1	1	1	1	
Exclusive Lane	0	0	0	0	0	0
Fuel	0	1	0	0	0	0=Gasoline, 1=Diesel

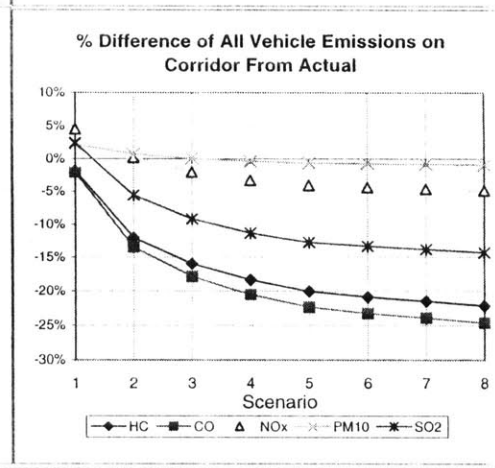
Colectivo Fare Structure and Avg. Trip Length	Trip Km	Fare	Observ.		Distance	
	0 - 5	$ 1.50	63.3%	0.950	5	3.165
	5 - 12	$ 2.00	20.4%	0.408	12	2.448
	12 - 17	$ 2.50	6.1%	0.153	17	1.037
	> 17	$ 2.50	10.2%	0.255	17	1.734
	Total		Avg. Fare	$1.77	Avg. Dist.	8.4











Corridor Test: Varying Colectivo Fare — 4-lane divided urban arterial (Class II)

	Hourly Peak Demand in One Direction (Pass.-Trips)	Fare ($ Pesos) Bus	Fare ($ Pesos) Col	Vehicle Capacity Bus	Vehicle Capacity Col	Headway Peak (min.) Bus	Headway Peak (min.) Col	Headway Off-Peak (min.) Bus	Headway Off-Peak (min.) Col	Colect. Occup. Col
Data:	5000	$1.00	$1.77	70	35	1.76	0.25	2.21	0.32	85%
SCENARIO 1	5000	$1.00	$1.00	70	35	1.76	0.52	2.21	0.73	85%
2	5000	$1.00	$1.25	70	35	1.76	0.54	2.21	0.77	85%
3	5000	$1.00	$1.50	70	35	1.76	0.58	2.21	0.83	85%
4	5000	$1.00	$1.75	70	35	1.76	0.64	2.21	0.91	85%
5	5000	$1.00	$2.00	70	35	1.76	0.72	2.21	1.03	85%
6	5000	$1.00	$2.25	70	35	1.76	0.84	2.21	1.19	85%
7	5000	$1.00	$2.50	70	35	1.76	1.00	2.21	1.43	85%
8	5000	$1.00	$2.75	70	35	1.76	1.26	2.21	1.82	85%

OPERATIONAL RESULTS

	Pk-Hr Pass. Mode Share (of R.B.P.T. Trips) Bus	Col	Passengers Per Day Bus	Col	Corridor LOS Peak	Off-Pk	VKT per Year on Corridor Bus	Col	Daily VKT per Vehicle Bus	Col	No. of Veh. Operating in Peak Bus	Col	No. of Veh. Operating in Off-Pk Bus	Col
Data	19.4%	80.6%	10163	42224	B	A	4,700,160	32,762,880	236	337	53	258	36	175
1	4.8%	95.2%	2512	49875	A	A	5,091,238	16,123,651	264	397	46	106	37	74
2	9.6%	90.4%	5042	47345	A	A	5,091,238	15,317,706	264	397	46	100	37	70
3	16.0%	84.0%	8370	44017	A	A	5,091,238	14,249,976	264	397	46	93	37	66
4	23.6%	76.4%	12350	40037	A	A	5,091,238	12,966,457	264	397	46	85	37	60
5	32.1%	67.9%	16840	35547	A	A	5,091,238	11,512,513	264	397	46	75	37	53
6	41.4%	58.6%	21699	30689	A	A	5,091,238	9,931,978	264	397	46	65	37	46
7	51.1%	48.9%	26794	25594	A	A	5,091,238	8,265,305	264	397	46	54	37	38
8	61.1%	38.9%	32009	20379	A	A	5,091,238	6,544,664	264	397	46	43	37	30

CORRIDOR PARAMETERS:

Theoretical Capacity (equiv. veh./hr)	3000	Length, one way (km)	15
Number of Hours in Peak Demand	6	% of Daily Traffic in the Peak Period	42%
Number of Hours in Off-Peak Demand	12	% of Traffic in Peak Direction	55%
% of Hourly Demand during Peak	100%	Avg. Hours of Colectivo Operations/Day	12
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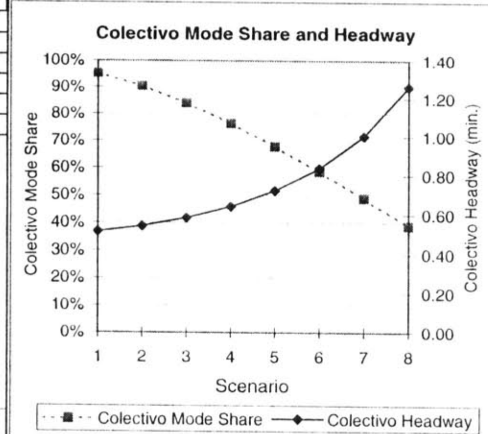
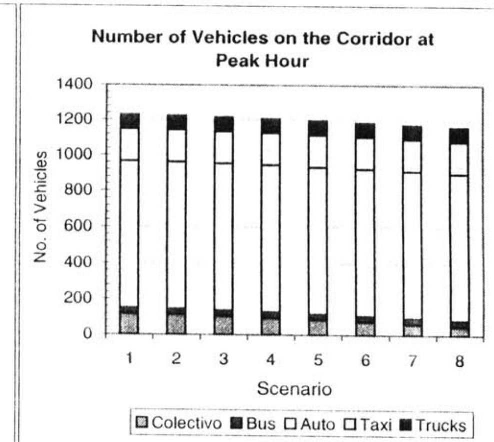
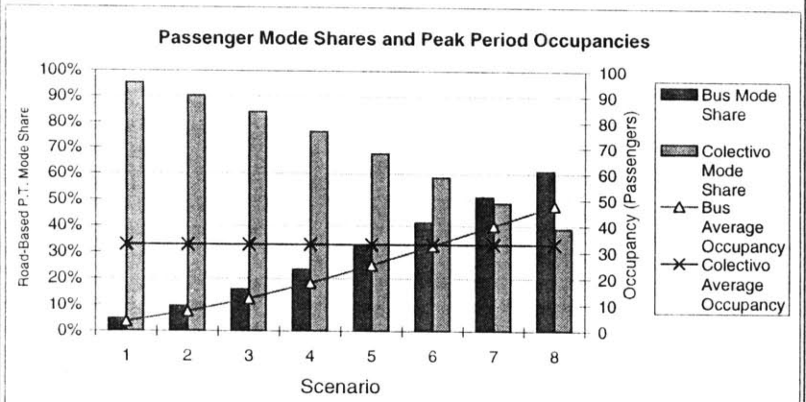
	Auto	Bus	Col	Taxi	Trucks	Total
Observed No. of Veh. (Pk Hr)	817	34	237	182	81	1351
Observed Vehicle Mode Share	60.5%	2.5%	17.5%	13.5%	6.0%	100%
Observed Pass. Mode Share	24.5%	14.1%	58.6%	2.7%	0.0%	100%
Value of Time (Pesos/hr)	$ 15	$ 10	$ 10	$ 15		
Avg. Speed (Kph)	45.6	19.6	29.1	45.6	45.6	
Mixed Lanes	1	1	1	1	1	
Exclusive Lane	0	0	0	0	0	0
Fuel	0	1	0	0	1	0=Gasoline, 1=Diesel

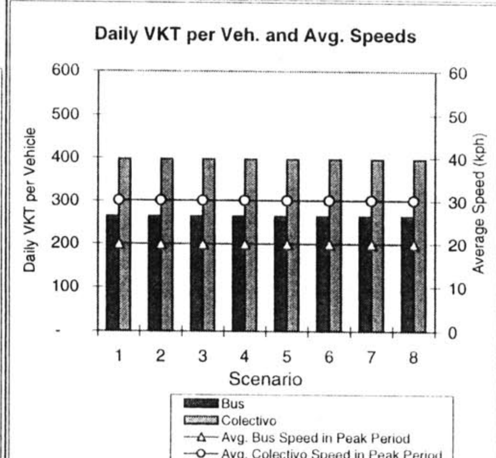
Colectivo Fare Structure and Avg. Trip Length	Trip Km	Fare	Observ.	
	0 - 5	$ 1.50	63.3%	0.950
	5 - 12	$ 2.00	20.4%	0.408
	12 - 17	$ 2.50	6.1%	0.153
	> 17	$ 2.50	10.2%	0.255
	Total		Avg. Fare	$1.77

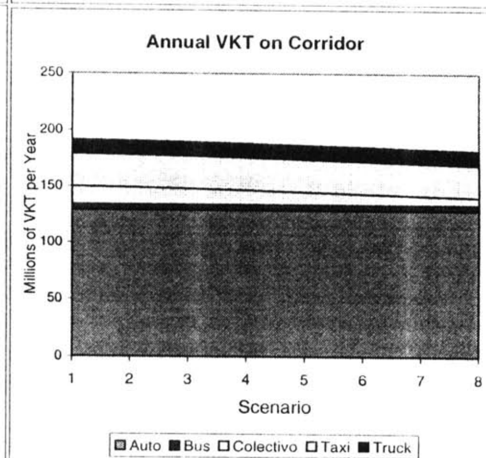
Distance	
5	3.165
12	2.448
17	1.037
17	1.734
Avg. Dist.	8.4











Corridor Test:	Varying Colectivo Fare	4-lane divided urban arterial (Class II)

		Hourly Peak Demand in One Direction (Pass.-Trips)	Fare ($ Pesos)		Vehicle Capacity		Headway Peak (min.)		Headway Off-Peak (min.)		Colect. Occup.
			Bus	Col	Bus	Col	Bus	Col	Bus	Col	Col
Data:		5000	$1.00	$1.77	70	35	1.76	0.25	2.21	0.32	85%
SCENARIO	1	5000	$1.00	$1.00	70	35	1.76	0.52	2.21	0.73	85%
	2	5000	$1.00	$1.25	70	35	1.76	0.54	2.21	0.77	85%
	3	5000	$1.00	$1.50	70	35	1.76	0.58	2.21	0.83	85%
	4	5000	$1.00	$1.75	70	35	1.76	0.64	2.21	0.91	85%
	5	5000	$1.00	$2.00	70	35	1.76	0.72	2.21	1.03	85%
	6	5000	$1.00	$2.25	70	35	1.76	0.84	2.21	1.19	85%
	7	5000	$1.00	$2.50	70	35	1.76	1.00	2.21	1.43	85%
	8	5000	$1.00	$2.75	70	35	1.76	1.26	2.21	1.82	85%

ECONOMIC RESULTS

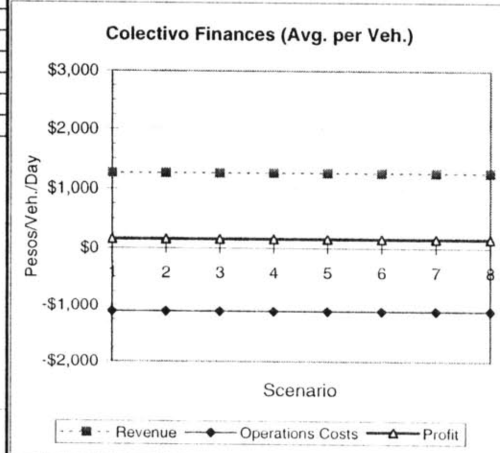
	Total Daily Costs (All Modes & Both Dir.)	Daily Delay in Pk. Dir. (hrs.)	Operational Cost per Veh. Per Day		Revenue per Veh. Per Day		Fleet Profitability per Day		Profit Per Vehicle Per Day		Profit/Loss Margin	
			Bus	Col	Bus	Col	Bus	Col	Bus	Col	Bus	Col
Data	$ 682,086	12,787	$ (2,054)	$ (1,008)	$ 297	$ 446	$ (109,298)	$ (170,580)	$ (1,757)	$ (562)	-85.5%	-55.7%
	-20.9%	72.2%					-43%	-59%	-43%	0%		
1	$ 539,558	5,785	$ (2,141)	$ (1,106)	$ 73	$ 1,264	$ (124,638)	$ 20,009	$ (2,068)	$ 158	-96.6%	14.3%
2	$ 568,285	6,136	$ (2,141)	$ (1,106)	$ 148	$ 1,264	$ (120,096)	$ 19,009	$ (1,993)	$ 158	-93.1%	14.3%
3	$ 596,326	6,601	$ (2,141)	$ (1,106)	$ 248	$ 1,264	$ (114,080)	$ 17,684	$ (1,893)	$ 158	-88.4%	14.3%
4	$ 622,362	7,160	$ (2,141)	$ (1,106)	$ 368	$ 1,264	$ (106,848)	$ 16,091	$ (1,773)	$ 158	-82.8%	14.3%
5	$ 645,335	7,794	$ (2,141)	$ (1,106)	$ 504	$ 1,264	$ (98,656)	$ 14,287	$ (1,637)	$ 158	-76.5%	14.3%
6	$ 664,443	8,483	$ (2,141)	$ (1,106)	$ 652	$ 1,264	$ (89,751)	$ 12,326	$ (1,489)	$ 158	-69.6%	14.3%
7	$ 679,136	9,209	$ (2,141)	$ (1,106)	$ 808	$ 1,264	$ (80,360)	$ 10,257	$ (1,333)	$ 158	-62.3%	14.3%
8	$ 689,082	9,959	$ (2,141)	$ (1,106)	$ 969	$ 1,264	$ (70,665)	$ 8,122	$ (1,173)	$ 158	-54.8%	14.3%

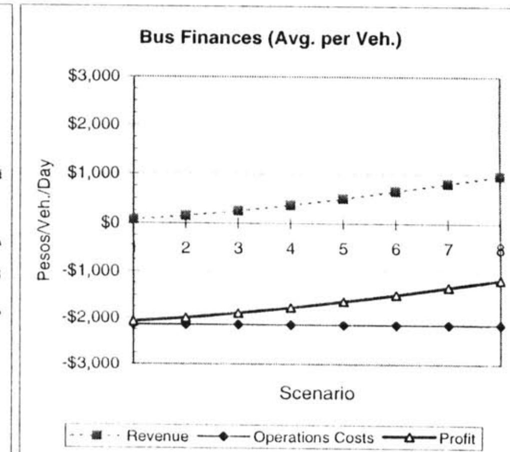
CORRIDOR PARAMETERS:

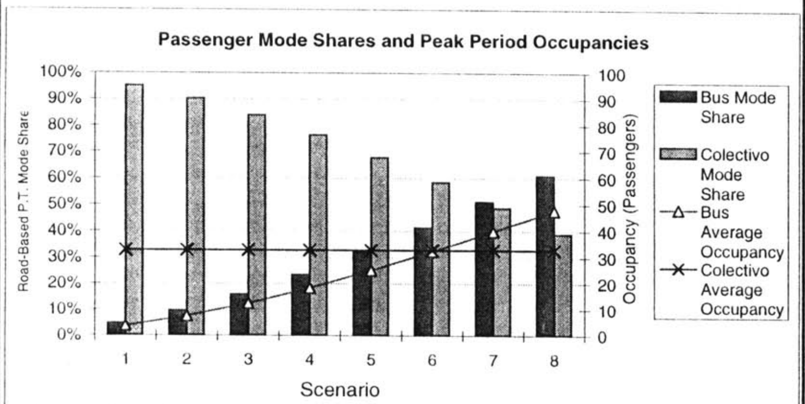
Theoretical Capacity (equiv. veh./hr)	3000	Length, one way (km)	15
Number of Hours in Peak Demand	6	% of Daily Traffic in the Peak Period	42%
Number of Hours in Off-Peak Demand	12	% of Traffic in Peak Direction	55%
% of Hourly Demand during Peak	100%	Avg. Hours of Colectivo Operations/Day	12
% of Hourly Demand during Off-Peak	70%	Number of Colectivo Workdays per Year	320

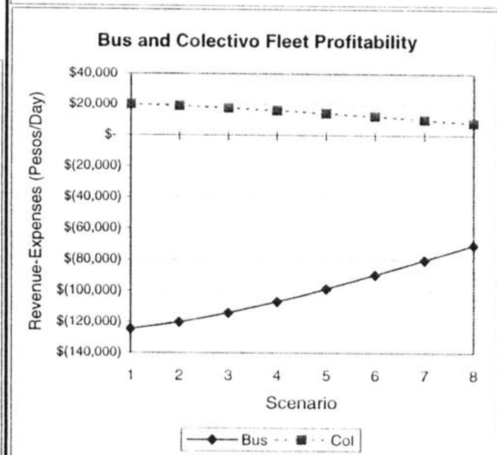
	Auto	Bus	Col	Taxi	Trucks	Total
Observed No. of Veh. (Pk Hr)	817	34	237	182	81	1351
Observed Vehicle Mode Share	60.5%	2.5%	17.5%	13.5%	6.0%	100%
Observed Pass. Mode Share	24.5%	14.1%	58.6%	2.7%	0.0%	100%
Value of Time (Pesos/hr)	$ 15	$ 10	$ 10	$ 15		
Avg. Speed (Kph)	45.6	19.6	29.1	45.6	45.6	
Mixed Lanes	1	1	1	1	1	
Exclusive Lane	0	0	0	0	0	0
Fuel	0	1	0	0	1	0=Gasoline, 1=Diesel

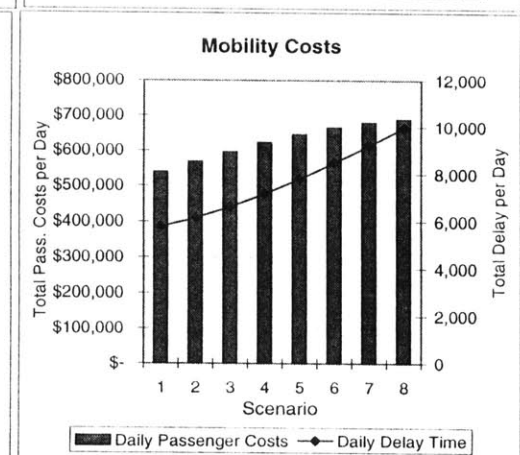
	Trip Km	Fare	Observ.		Distance	
Colectivo Fare Structure and Avg. Trip Length	0 - 5	$ 1.50	63.3%	0.950	5	3.165
	5 - 12	$ 2.00	20.4%	0.408	12	2.448
	12 - 17	$ 2.50	6.1%	0.153	17	1.037
	> 17	$ 2.50	10.2%	0.255	17	1.734
	Total		Avg. Fare	$1.77	Avg. Dist.	8.4











Corridor Test:	Varying Colectivo Fare	4-lane divided urban arterial (Class II)

	Hourly Peak Demand in One Direction (Pass.-Trips)	Fare ($ Pesos)		Vehicle Capacity		Headway Peak (min.)		Headway Off-Peak (min.)		Colect. Occup.
		Bus	Col	Bus	Col	Bus	Col	Bus	Col	Col
Data:	5000	$1.00	$1.77	70	35	1.76	0.25	2.21	0.32	85%
SCENARIO 1	5000	$1.00	$1.00	70	35	1.76	0.52	2.21	0.73	85%
2	5000	$1.00	$1.25	70	35	1.76	0.54	2.21	0.77	85%
3	5000	$1.00	$1.50	70	35	1.76	0.58	2.21	0.83	85%
4	5000	$1.00	$1.75	70	35	1.76	0.64	2.21	0.91	85%
5	5000	$1.00	$2.00	70	35	1.76	0.72	2.21	1.03	85%
6	5000	$1.00	$2.25	70	35	1.76	0.84	2.21	1.19	85%
7	5000	$1.00	$2.50	70	35	1.76	1.00	2.21	1.43	85%
8	5000	$1.00	$2.75	70	35	1.76	1.26	2.21	1.82	85%

ENVIRONMENTAL RESULTS

	HC (metric tons)		CO (metric tons)		NOx (metric tons)		PM10 (metric tons)		SO2 (metric tons)		Share of All Emissions		Emissions - All Vehicles (m.tons)	Total Daily Demand (pass.trips)
	Bus	Col	Bus	Col	Bus	Col	Bus	Col	Bus	Col	Bus	Col		
Data	40.58	163.47	109.33	1794.31	102.65	59.84	7.05	0.95	1.48	3.77	2.8%	21.7%	9,299	72,000
											0.3%	-6.9%	% Δ	
1	43.96	78.05	118.43	860.00	111.20	30.05	7.64	0.47	1.61	1.85	3.6%	12.2%	-14%	72,000
2	43.96	74.15	118.43	817.02	111.20	28.55	7.64	0.44	1.61	1.76	3.6%	11.6%	-15%	72,000
3	43.96	68.98	118.43	760.07	111.20	26.56	7.64	0.41	1.61	1.64	3.6%	10.9%	-16%	72,000
4	43.96	62.77	118.43	691.60	111.20	24.17	7.64	0.38	1.61	1.49	3.6%	10.0%	-16%	72,000
5	43.96	55.73	118.43	614.05	111.20	21.46	7.64	0.33	1.61	1.32	3.7%	9.0%	-17%	72,000
6	43.96	48.08	118.43	529.75	111.20	18.51	7.64	0.29	1.61	1.14	3.7%	7.9%	-18%	72,000
7	43.96	40.01	118.43	440.85	111.20	15.41	7.64	0.24	1.61	0.95	3.8%	6.6%	-19%	72,000
8	43.96	31.68	118.43	349.08	111.20	12.20	7.64	0.19	1.61	0.75	3.8%	5.3%	-21%	72,000

CORRIDOR PARAMETERS:

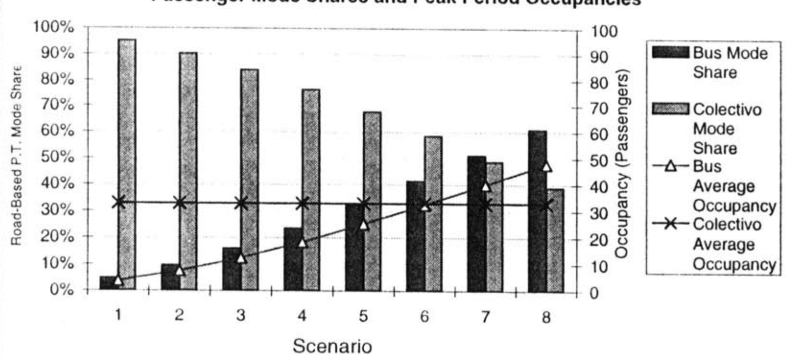
Theoretical Capacity (equiv. veh./hr)	3000	Length, one way (km)	15
Number of Hours in Peak Demand	6	% of Daily Traffic in the Peak Period	42%
Number of Hours in Off-Peak Demand	12	% of Traffic in Peak Direction	55%
% of Hourly Demand during Peak	100%	Avg. Hours of Colectivo Operations/Day	12
% of Hourly Demand during Off-Peak	70%	Number of Colectivo Workdays per Year	320

	Auto	Bus	Col	Taxi	Trucks	Total
Observed No. of Veh. (Pk Hr)	817	34	237	182	81	1351
Observed Vehicle Mode Share	60.5%	2.5%	17.5%	13.5%	6.0%	100%
Observed Pass. Mode Share	24.5%	14.1%	58.6%	2.7%	0.0%	100%
Value of Time (Pesos/hr)	$ 15	$ 10	$ 10	$ 15		
Avg. Speed (Kph)	45.6	19.6	29.1	45.6	45.6	
Mixed Lanes	1	1	1	1	1	
Exclusive Lane	0	0	0	0	0	0
Fuel	0	1	0	0	1	0=Gasoline, 1=Diesel

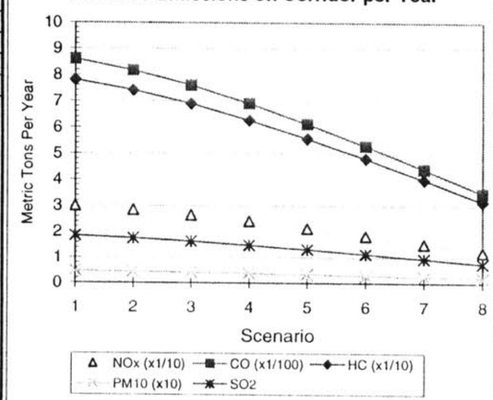
	Trip Km	Fare	Observ.	
Colectivo Fare Structure and Avg. Trip Length	0 - 5	$ 1.50	63.3%	0.950
	5 - 12	$ 2.00	20.4%	0.408
	12 - 17	$ 2.50	6.1%	0.153
	> 17	$ 2.50	10.2%	0.255
	Total		Avg. Fare	$1.77

Distance	
5	3.165
12	2.448
17	1.037
17	1.734
Avg. Dist.	8.4

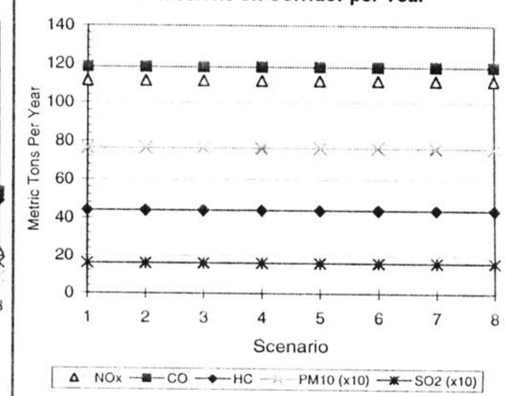
Passenger Mode Shares and Peak Period Occupancies



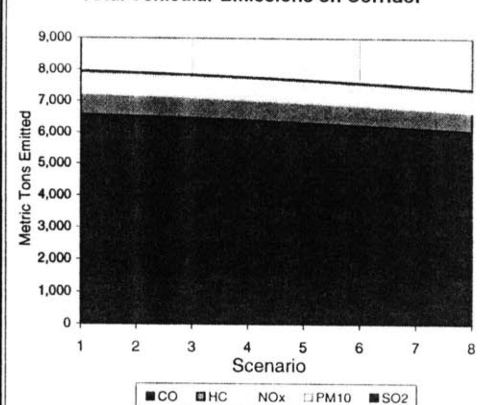
Colectivo Emissions on Corridor per Year



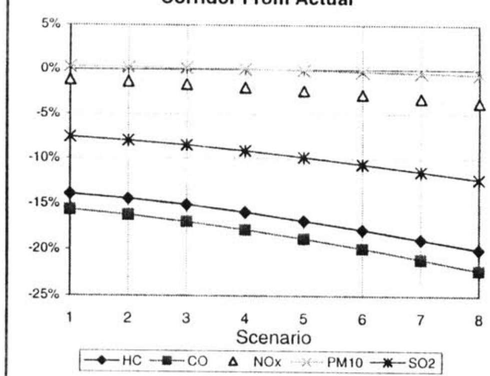
Bus Emissions on Corridor per Year



Total Vehicular Emissions on Corridor



% Difference of All Vehicle Emissions on Corridor From Actual



Corridor Test: Varying Bus Frequency — 4-lane divided urban arterial (Class II)

	Hourly Peak Demand in One Direction (Pass.-Trips)	Fare ($ Pesos) Bus	Fare ($ Pesos) Col	Vehicle Capacity Bus	Vehicle Capacity Col	Headway Peak (min.) Bus	Headway Peak (min.) Col	Headway Off-Peak (min.) Bus	Headway Off-Peak (min.) Col	Colect. Occup. Col
Data:	5000	$1.00	$1.77	70	35	1.76	0.25	2.21	0.32	85%
SCENARIO 1	5000	$1.00	$1.77	70	35	1.00	0.67	2.00	0.93	85%
2	5000	$1.00	$1.77	70	35	2.00	0.64	4.00	0.87	85%
3	5000	$1.00	$1.77	70	35	3.00	0.62	6.00	0.82	85%
4	5000	$1.00	$1.77	70	35	4.00	0.60	8.00	0.78	85%
5	5000	$1.00	$1.77	70	35	5.00	0.58	10.00	0.75	85%
6	5000	$1.00	$1.77	70	35	6.00	0.57	12.00	0.73	85%
7	5000	$1.00	$1.77	70	35	7.00	0.55	14.00	0.71	85%
8	5000	$1.00	$1.77	70	35	8.00	0.54	16.00	0.71	85%

OPERATIONAL RESULTS

	Pk-Hr Pass. Mode Share (of R.B.P.T. Trips) Bus	Pk-Hr Pass. Mode Share Col	Passengers Per Day Bus	Passengers Per Day Col	Corridor LOS Peak	Corridor LOS Off-Pk	VKT per Year on Corridor Bus	VKT per Year on Corridor Col	Daily VKT per Vehicle Bus	Daily VKT per Vehicle Col	No. of Veh. Operating in Peak Bus	No. of Veh. Operating in Peak Col	No. of Veh. Operating in Off-Pk Bus	No. of Veh. Operating in Off-Pk Col
Data	19.4%	80.6%	10163	42224	B	A	4,700,160	32,762,880	236	337	53	258	36	175
1	26.3%	73.7%	13797	38590	A	A	6,912,000	12,650,237	264	397	82	82	41	59
2	23.6%	76.4%	12350	40037	A	A	3,456,000	13,367,469	264	397	41	85	20	63
3	20.9%	79.1%	10960	41427	A	A	2,304,000	14,025,843	264	397	27	88	14	67
4	18.4%	81.6%	9631	42756	A	A	1,728,000	14,616,848	264	397	20	90	10	70
5	16.0%	84.0%	8370	44017	A	A	1,382,400	15,131,900	264	397	16	93	8	72
6	13.7%	86.3%	7181	45206	A	A	1,152,000	15,562,397	264	397	14	96	7	75
7	11.6%	88.4%	6070	46317	A	A	987,429	15,899,765	264	397	12	98	6	76
8	9.6%	90.4%	5042	47345	A	A	864,000	16,135,513	264	397	10	100	5	77

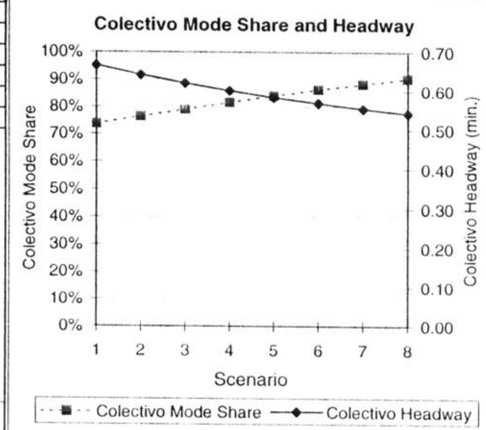
CORRIDOR PARAMETERS:

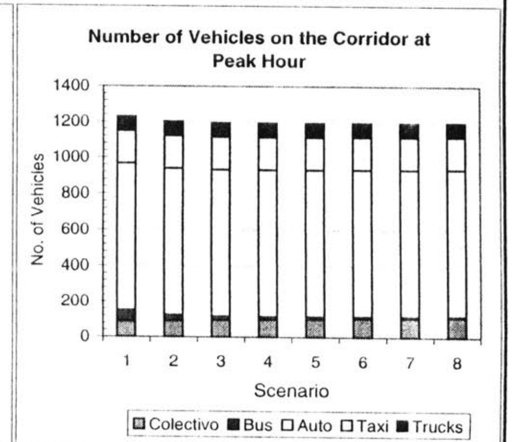
Theoretical Capacity (equiv. veh./hr)	3000	Length, one way (km)	15
Number of Hours in Peak Demand	6	% of Daily Traffic in the Peak Period	42%
Number of Hours in Off-Peak Demand	12	% of Traffic in Peak Direction	55%
% of Hourly Demand during Peak	100%	Avg. Hours of Colectivo Operations/Day	12
% of Hourly Demand during Off-Peak	70%	Number of Colectivo Workdays per Year	320

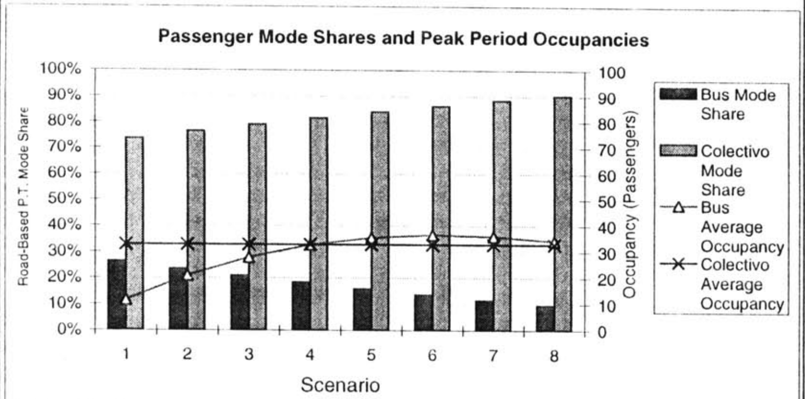
	Auto	Bus	Col	Taxi	Trucks	Total
Observed No. of Veh. (Pk Hr)	817	34	237	182	81	1351
Observed Vehicle Mode Share	60.5%	2.5%	17.5%	13.5%	6.0%	100%
Observed Pass. Mode Share	24.5%	14.1%	58.6%	2.7%	0.0%	100%
Value of Time (Pesos/hr)	$ 15	$ 10	$ 10	$ 15		
Avg. Speed (Kph)	45.6	19.6	29.1	45.6	45.6	
Mixed Lanes	1	1	1	1	1	
Exclusive Lane	0	0	0	0	0	0
Fuel	0	1	0	0	1	0=Gasoline, 1=Diesel

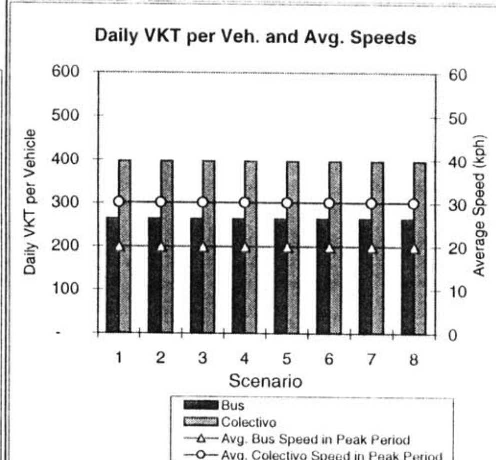
Colectivo Fare Structure and Avg. Trip Length	Trip Km	Fare	Observ.	
	0 - 5	$ 1.50	63.3%	0.950
	5 - 12	$ 2.00	20.4%	0.408
	12 - 17	$ 2.50	6.1%	0.153
	> 17	$ 2.50	10.2%	0.255
	Total		**Avg. Fare**	**$1.77**

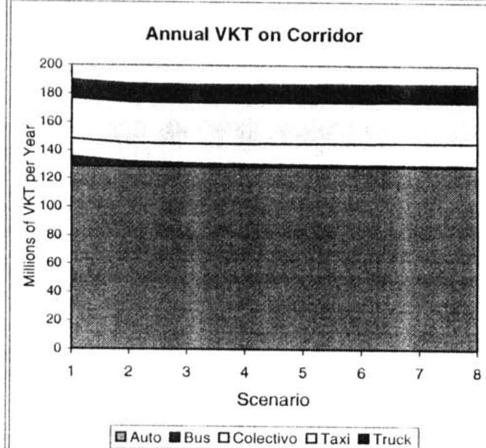
Distance	
5	3.165
12	2.448
17	1.037
17	1.734
Avg. Dist.	**8.4**











Corridor Test:	Varying Bus Frequency	4-lane divided urban arterial (Class II)

		Hourly Peak Demand in One Direction (Pass.-Trips)	Fare ($ Pesos)		Vehicle Capacity		Headway Peak (min.)		Headway Off-Peak (min.)		Colect. Occup.
			Bus	Col	Bus	Col	Bus	Col	Bus	Col	Col
Data:		5000	$1.00	$1.77	70	35	1.76	0.25	2.21	0.32	85%
S	1	5000	$1.00	$1.77	70	35	1.00	0.67	2.00	0.93	85%
C	2	5000	$1.00	$1.77	70	35	2.00	0.64	4.00	0.87	85%
E	3	5000	$1.00	$1.77	70	35	3.00	0.62	6.00	0.82	85%
N	4	5000	$1.00	$1.77	70	35	4.00	0.60	8.00	0.78	85%
A	5	5000	$1.00	$1.77	70	35	5.00	0.58	10.00	0.75	85%
R	6	5000	$1.00	$1.77	70	35	6.00	0.57	12.00	0.73	85%
I	7	5000	$1.00	$1.77	70	35	7.00	0.55	14.00	0.71	85%
O	8	5000	$1.00	$1.77	70	35	8.00	0.54	16.00	0.71	85%

ECONOMIC RESULTS

	Total Daily Costs (All Modes & Both Dir.)	Daily Delay in Pk. Dir. (hrs.)	Operational Cost per Veh. Per Day		Revenue per Veh. Per Day		Fleet Profitability per Day		Profit Per Vehicle Per Day		Profit/Loss Margin	
			Bus	Col	Bus	Col	Bus	Col	Bus	Col	Bus	Col
Data	$ 682,086	12,787	$ (2,054)	$ (1,008)	$ 297	$ 446	$ (109,298)	$ (170,580)	$ (1,757)	$ (562)	-85.5%	-55.7%
	-8.5%	-20.8%					-88%	28%	-7%	0%		
1	$ 624,345	7,298	$ (2,141)	$ (1,106)	$ 293	$ 1,264	$ (151,214)	$ 15,699	$ (1,848)	$ 158	-86.3%	14.3%
2	$ 623,734	6,986	$ (2,141)	$ (1,106)	$ 487	$ 1,264	$ (67,662)	$ 16,589	$ (1,654)	$ 158	-77.2%	14.3%
3	$ 622,326	6,699	$ (2,141)	$ (1,106)	$ 595	$ 1,264	$ (42,174)	$ 17,406	$ (1,546)	$ 158	-72.2%	14.3%
4	$ 620,335	6,441	$ (2,141)	$ (1,106)	$ 630	$ 1,264	$ (30,905)	$ 18,139	$ (1,511)	$ 158	-70.6%	14.3%
5	$ 618,009	6,217	$ (2,141)	$ (1,106)	$ 610	$ 1,264	$ (25,048)	$ 18,779	$ (1,531)	$ 158	-71.5%	14.3%
6	$ 615,627	6,029	$ (2,141)	$ (1,106)	$ 555	$ 1,264	$ (21,634)	$ 19,313	$ (1,587)	$ 158	-74.1%	14.3%
7	$ 613,499	5,882	$ (2,141)	$ (1,106)	$ 484	$ 1,264	$ (19,364)	$ 19,732	$ (1,657)	$ 158	-77.4%	14.3%
8	$ 611,962	5,780	$ (2,141)	$ (1,106)	$ 424	$ 1,264	$ (17,564)	$ 20,024	$ (1,717)	$ 158	-80.2%	14.3%

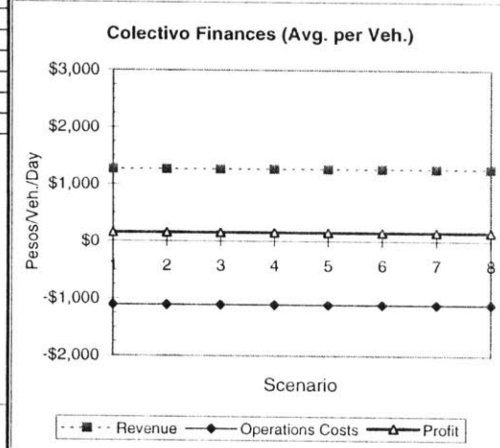
CORRIDOR PARAMETERS:

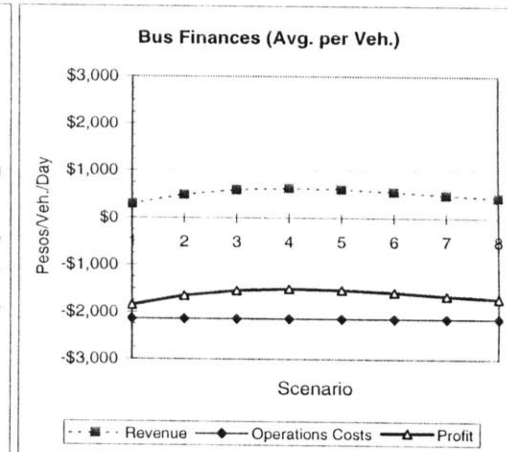
Theoretical Capacity (equiv. veh./hr)	3000	Length, one way (km)	15
Number of Hours in Peak Demand	6	% of Daily Traffic in the Peak Period	42%
Number of Hours in Off-Peak Demand	12	% of Traffic in Peak Direction	55%
% of Hourly Demand during Peak	100%	Avg. Hours of Colectivo Operations/Day	12
% of Hourly Demand during Off-Peak	70%	Number of Colectivo Workdays per Year	320

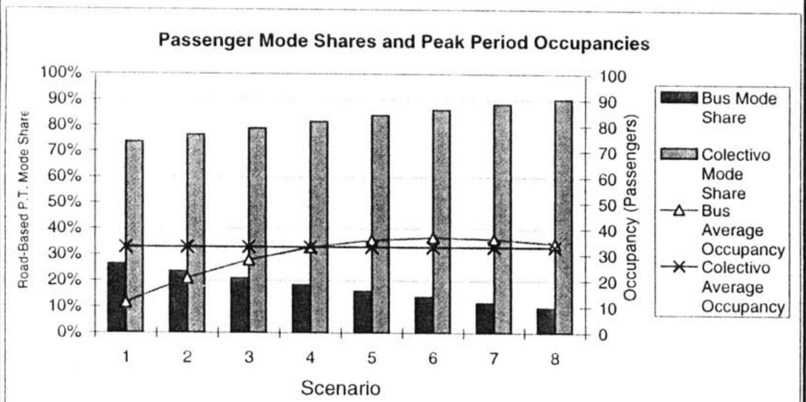
	Auto	Bus	Col	Taxi	Trucks	Total
Observed No. of Veh. (Pk Hr)	817	34	237	182	81	1351
Observed Vehicle Mode Share	60.5%	2.5%	17.5%	13.5%	6.0%	100%
Observed Pass. Mode Share	24.5%	14.1%	58.6%	2.7%	0.0%	100%
Value of Time (Pesos/hr)	$ 15	$ 10	$ 10	$ 15		
Avg. Speed (Kph)	45.6	19.6	29.1	45.6	45.6	
Mixed Lanes	1	1	1	1	1	
Exclusive Lane	0	0	0	0	0	0
Fuel	0	1	0	0	1	0=Gasoline, 1=Diesel

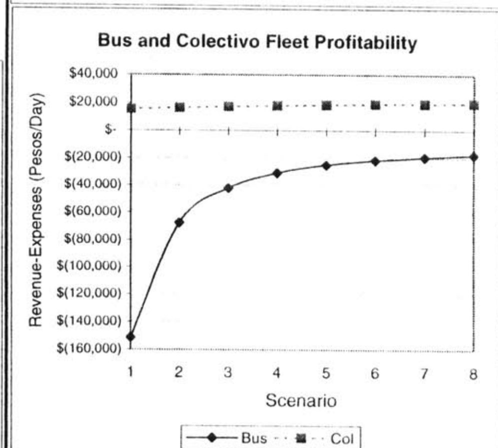
	Trip Km	Fare	Observ.	
Colectivo	0 - 5	$ 1.50	63.3%	0.950
Fare Structure	5 - 12	$ 2.00	20.4%	0.408
and Avg. Trip	12 - 17	$ 2.50	6.1%	0.153
Length	> 17	$ 2.50	10.2%	0.255
	Total		Avg. Fare	$1.77

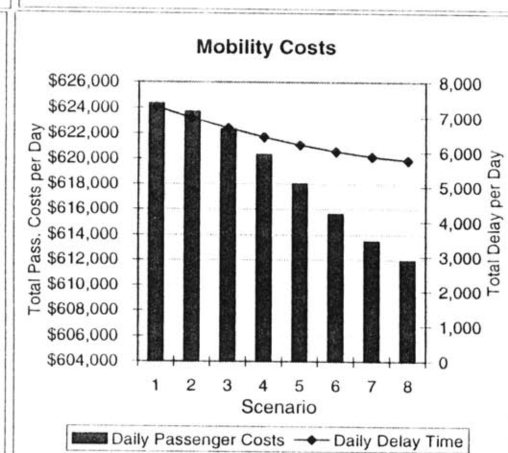
	Distance	
	5	3.165
	12	2.448
	17	1.037
	17	1.734
Avg. Dist.		8.4











Corridor Test: Varying Bus Frequency — 4-lane divided urban arterial (Class II)

	Hourly Peak Demand in One Direction (Pass.-Trips)	Fare ($ Pesos) Bus	Fare ($ Pesos) Col	Vehicle Capacity Bus	Vehicle Capacity Col	Headway Peak (min.) Bus	Headway Peak (min.) Col	Headway Off-Peak (min.) Bus	Headway Off-Peak (min.) Col	Colect. Occup. Col
Data:	5000	$1.00	$1.77	70	35	1.76	0.25	2.21	0.32	85%
SCENARIO 1	5000	$1.00	$1.77	70	35	1.00	0.67	2.00	0.93	85%
2	5000	$1.00	$1.77	70	35	2.00	0.64	4.00	0.87	85%
3	5000	$1.00	$1.77	70	35	3.00	0.62	6.00	0.82	85%
4	5000	$1.00	$1.77	70	35	4.00	0.60	8.00	0.78	85%
5	5000	$1.00	$1.77	70	35	5.00	0.58	10.00	0.75	85%
6	5000	$1.00	$1.77	70	35	6.00	0.57	12.00	0.73	85%
7	5000	$1.00	$1.77	70	35	7.00	0.55	14.00	0.71	85%
8	5000	$1.00	$1.77	70	35	8.00	0.54	16.00	0.71	85%

ENVIRONMENTAL RESULTS

	HC (metric tons) Bus	HC Col	CO (metric tons) Bus	CO Col	NOx (metric tons) Bus	NOx Col	PM10 (metric tons) Bus	PM10 Col	SO2 (metric tons) Bus	SO2 Col	Share of All Emissions Bus	Share of All Emissions Col	Emissions - All Vehicles (m.tons)	Total Daily Demand (pass.trips)
Data	40.58	163.47	109.33	1794.31	102.65	59.84	7.05	0.95	1.48	3.77	2.8%	21.7%	9,299	72,000
											-4.3%	2.9%	% Δ	
1	59.68	61.24	160.78	674.74	150.96	23.58	10.37	0.37	2.18	1.45	4.9%	9.7%	-16%	72,000
2	29.84	64.71	80.39	712.99	75.48	24.92	5.18	0.39	1.09	1.54	2.5%	10.4%	-17%	72,000
3	19.89	67.90	53.59	748.11	50.32	26.14	3.46	0.41	0.73	1.61	1.7%	11.0%	-17%	72,000
4	14.92	70.76	40.19	779.63	37.74	27.25	2.59	0.42	0.55	1.68	1.2%	11.4%	-17%	72,000
5	11.94	73.25	32.16	807.11	30.19	28.21	2.07	0.44	0.44	1.74	1.0%	11.8%	-17%	72,000
6	9.95	75.34	26.80	830.07	25.16	29.01	1.73	0.45	0.36	1.79	0.8%	12.1%	-17%	72,000
7	8.53	76.97	22.97	848.06	21.57	29.64	1.48	0.46	0.31	1.83	0.7%	12.4%	-17%	72,000
8	7.46	78.11	20.10	860.64	18.87	30.08	1.30	0.47	0.27	1.86	0.6%	12.6%	-17%	72,000

CORRIDOR PARAMETERS:

Theoretical Capacity (equiv. veh./hr)	3000	Length, one way (km)	15
Number of Hours in Peak Demand	6	% of Daily Traffic in the Peak Period	42%
Number of Hours in Off-Peak Demand	12	% of Traffic in Peak Direction	55%
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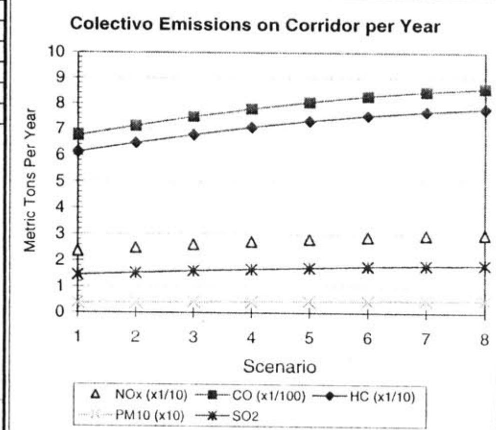
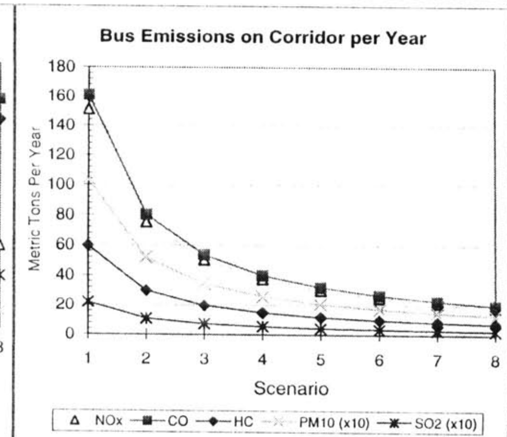
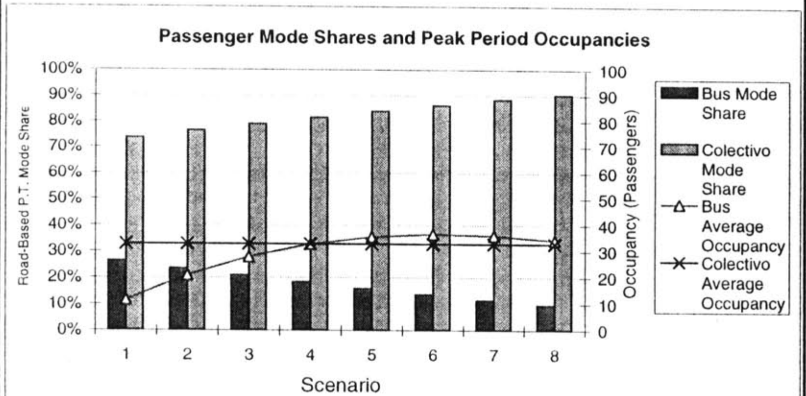
Value of Time (Pesos/hr)	$ 15	$ 10	$ 10	$ 15		
Avg. Speed (Kph)	45.6	19.6	29.1	45.6	45.6	
Mixed Lanes	1	1	1	1	1	
Exclusive Lane	0	0	0	0	0	0
Fuel	0	1	0	0	1	0=Gasoline, 1=Diesel

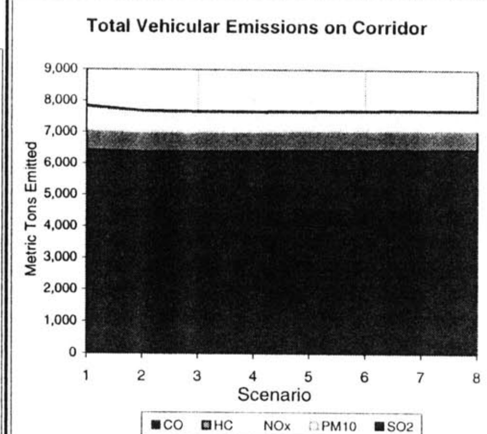
Colectivo Fare Structure and Avg. Trip Length	Trip Km	Fare	Observ.	
	0 - 5	$ 1.50	63.3%	0.950
	5 - 12	$ 2.00	20.4%	0.408
	12 - 17	$ 2.50	6.1%	0.153
	> 17	$ 2.50	10.2%	0.255
	Total		Avg. Fare	$1.77

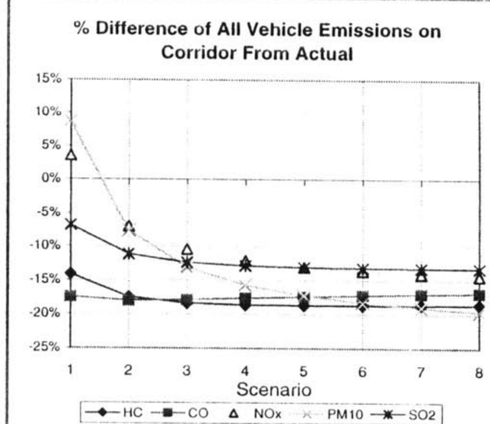
Distance	
5	3.165
12	2.448
17	1.037
17	1.734
Avg. Dist.	8.4





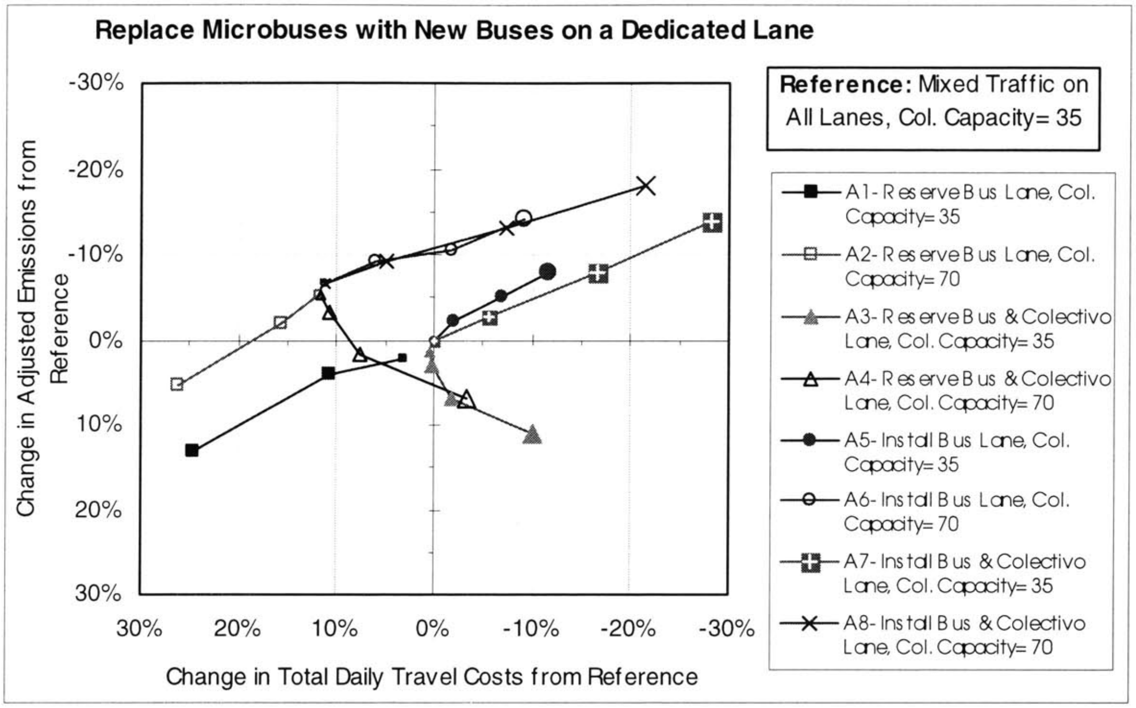






Appendix B: Combining Strategies with a Dedicated Lane

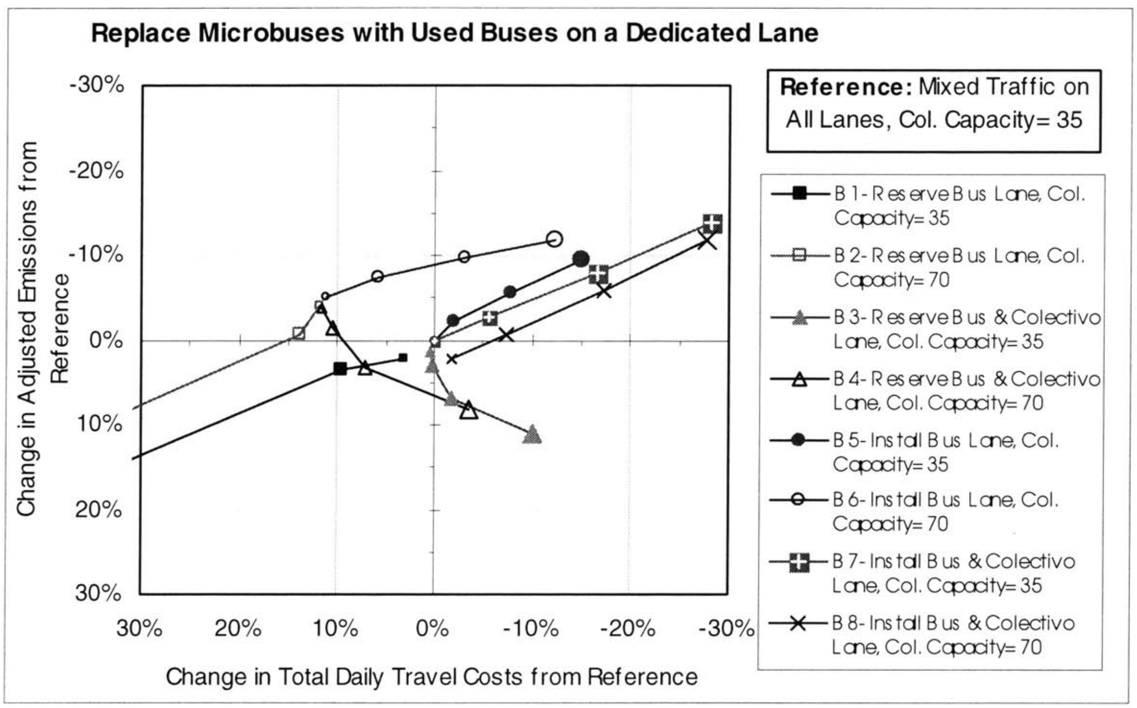
Replacing Colectivos with New Buses (Option A):



Under this scenario, the win-win strategies always include installing a new bus or bus/colectivo lane (A5-A8). The significance always improves for these with increasing congestion. However, installing a lane and replacing colectivos with buses may have a significant negative impact on mobility if the original roadway condition was uncongested (A6 & A8).

As expected, mobility decreases and emissions increase when colectivos are replaced with buses. However, reserving a lane may actually increase emissions unless done under uncongested conditions (A1-A4). As expected, installing an additional lane is always beneficial to both mobility and emissions if the effect of induced demand is not considered. In fact, replacing colectivos with buses only improves mobility if done in conjunction with installing a new bus or bus/colectivo lane (A5-A6 & A7-A8). Under uncongested conditions, it is possible to reduce emissions slightly by reserving a lane for buses or both buses and colectivos, (A2 & A4). In addition, mobility improves with a reserved lane only if both buses and colectivos are included and under congested conditions (A3-A4). In general, increasing congestion increases the effectiveness of this set of options. However, reserving a lane for buses only is generally a loss-loss strategy (A1-A2).

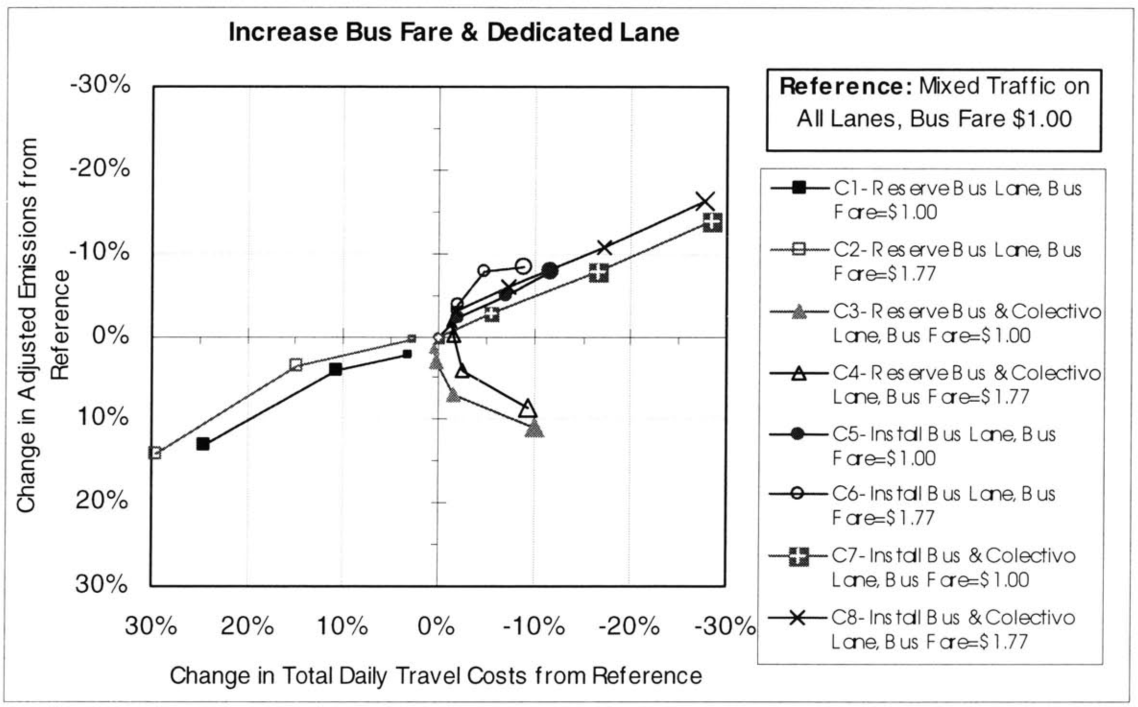
Replacing Colectivos with Used Buses (Option B):



Again, the win-win strategies always include installing a new bus or bus/colectivo lane (B5-B8) and the significance always improves for these with increasing congestion. However, installing a bus lane and replacing colectivos with buses may have a significant negative impact on mobility if the original roadway condition was uncongested (B6).

Again, mobility generally improves when colectivos are replaced with used buses and the emissions improvements obviously become less resounding. One surprising result is that replacing the colectivos with used buses in conjunction with an installed bus/colectivo lane may actually reduce emissions slightly less than if colectivos remained at a capacity of 35 (B7-B8). This result is highly dependent on the emissions characteristics of the colectivos and buses being studied, and therefore will not be true in a general sense. As in Section 3.5.1, reserving a lane is likely to actually increase emissions, especially in congested conditions (B1-B4). As expected, installing an additional lane is always beneficial to both mobility and emissions. In addition, mobility improves with a reserved lane only if both buses and colectivos are included and under congested conditions (B3-B4). Reserving a lane for buses only is generally a loss-loss strategy (B1-B2).

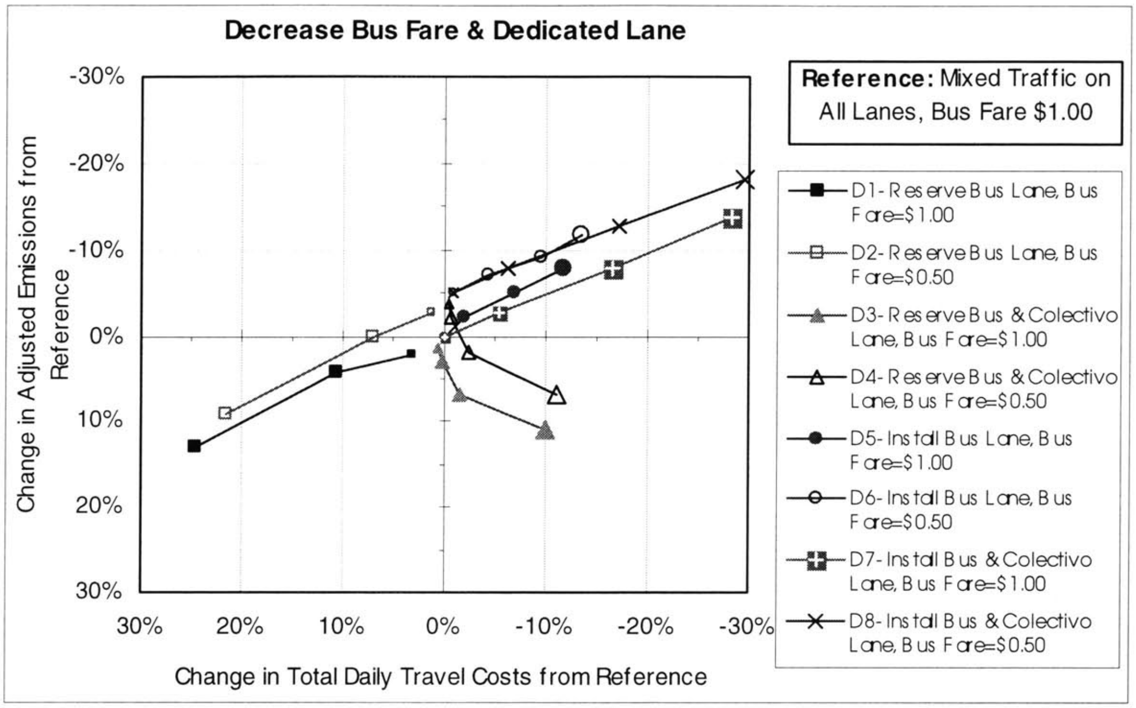
Increasing the Bus Fare (Option C):



As with the previous scenarios, the most effective win-win strategies are installing a lane for both buses and colectivos under originally congested conditions. This scenario shows that it may be possible to offset the capital cost of installing a lane by increasing the bus fare while maintaining significant improvements in mobility and emissions. In addition, reserving a lane for buses only is always a loss-loss strategy under this scenario (C1-C2).

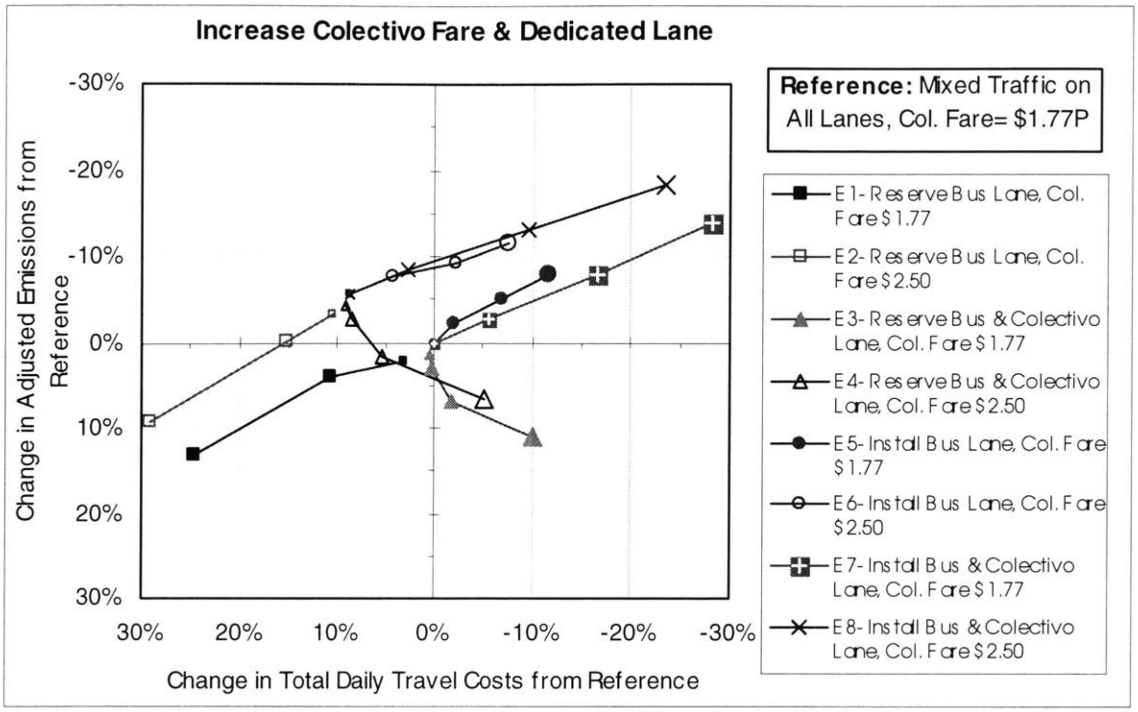
Especially under congested conditions, reserving a lane generally increases emissions (C1-C4).

Decreasing the Bus Fare (Option D):



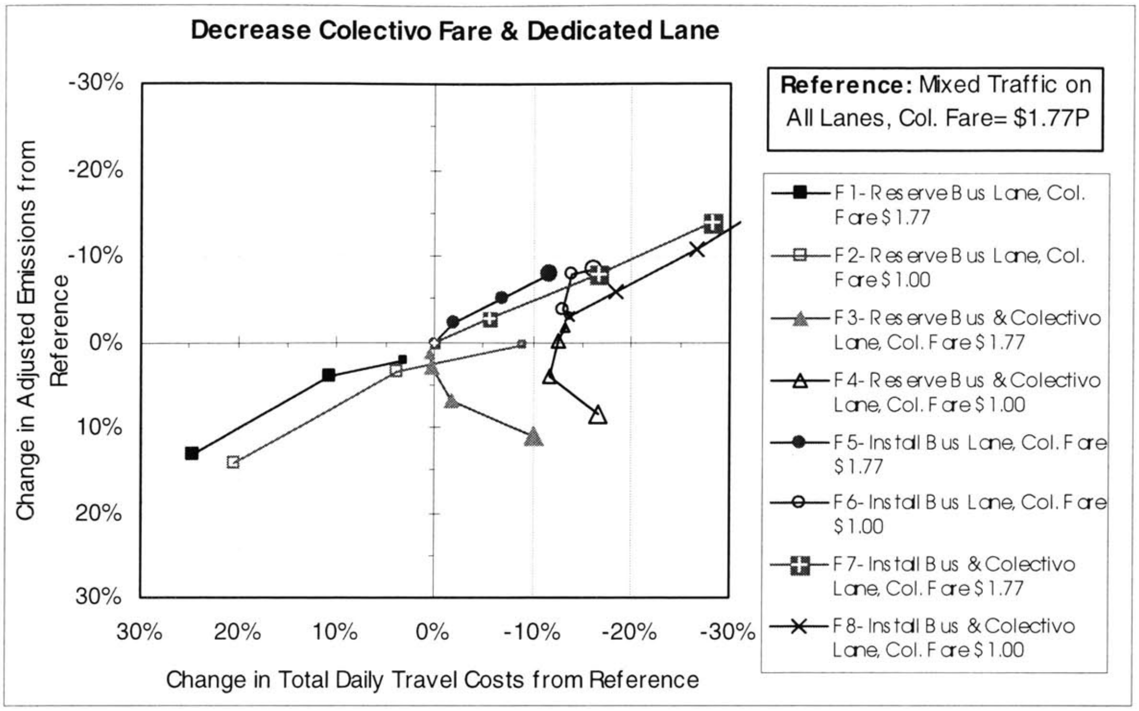
As expected, decreasing the bus fare improves mobility slightly by reducing overall trip costs in all cases. As with the previous scenarios, reserving a lane only improves mobility significantly if it includes both buses and colectivos and under originally congested conditions (D3-D4).

Increasing the Average Colectivo Fare (Option E):



In general, varying the colectivo fare has the same impact on emissions and mobility as varying the bus fare. The difference, of course, is that the revenues for each mode are distributed differently.

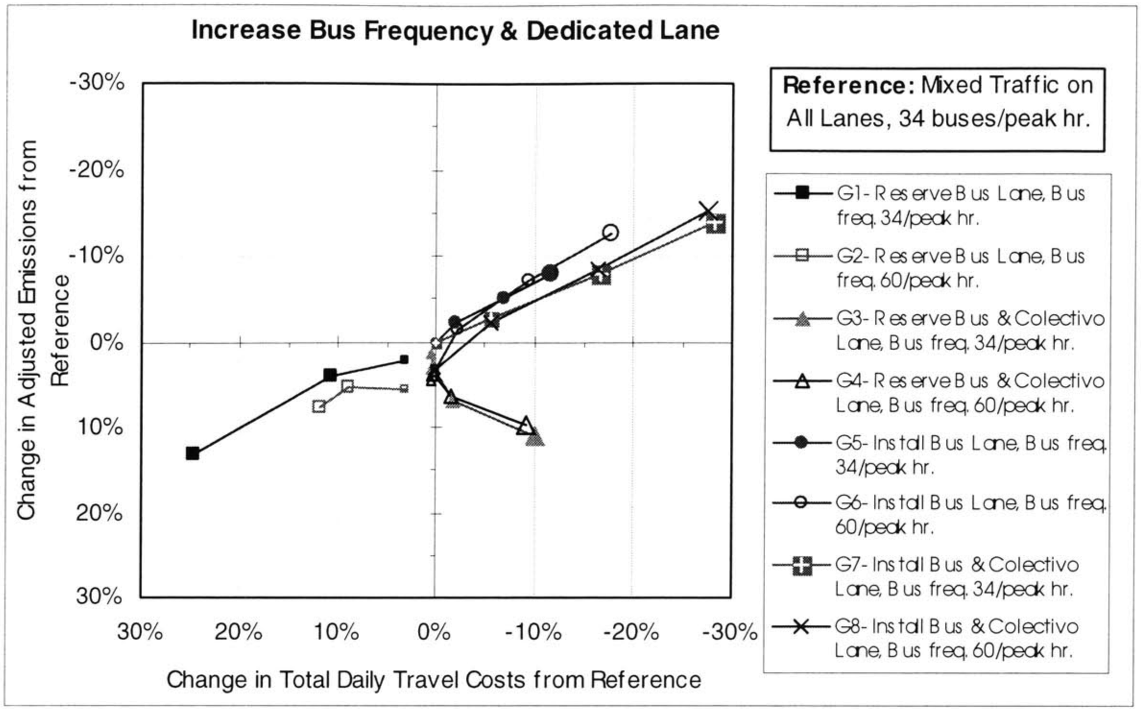
Decreasing the Average Colectivo Fare (Option F):



Decreasing the average colectivo fare results in significant improvements in mobility. One interesting result is that installing a new exclusive bus lane is a win-win strategy under all conditions (F6) where

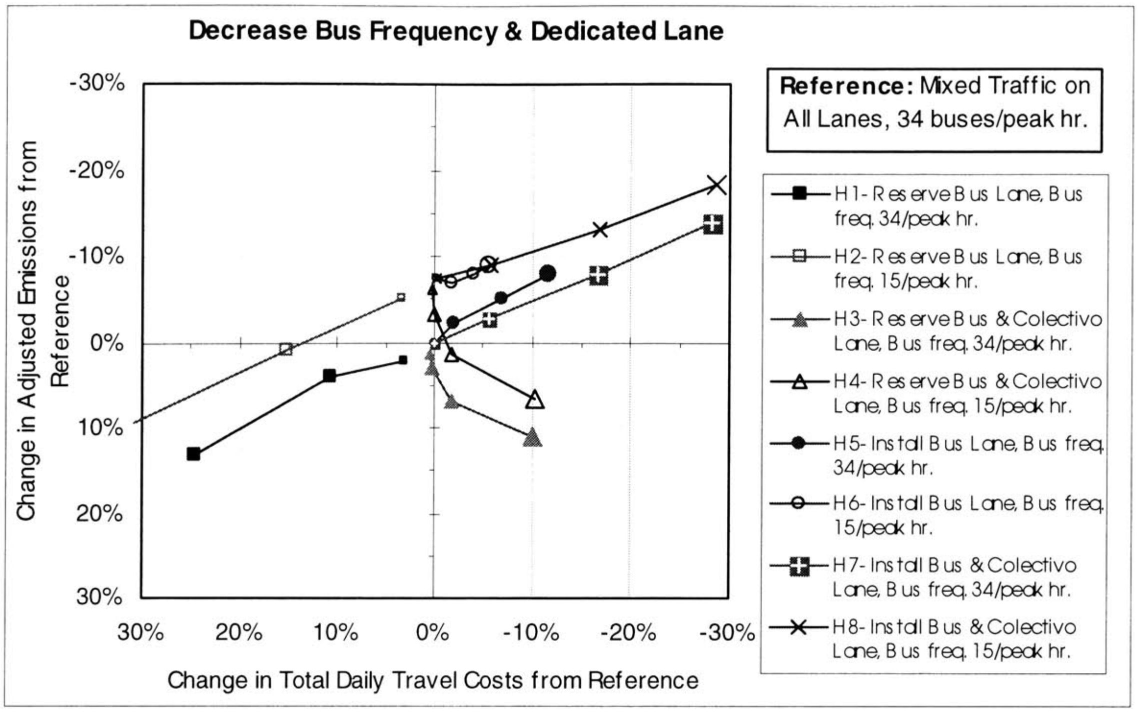
In essence, segmenting the markets between buses and colectivos. The preferred mode from an emissions perspective could operate faster in the dedicated lane and charge a fare premium while the other mode negotiates traffic in the mixed lanes for a lower fare.

Increasing Bus Service Frequency (Option G):



In general, these results confirm that increasing the bus frequency has little impact on mobility and emissions under any of the options tested (G1-G8). Especially under congested conditions, increasing the bus frequency alone is not enough to improve the competitiveness of the bus with the colectivo unless the buses are running on a dedicate lane.

Decreasing Bus Service Frequency (Option H):



Decreasing bus frequency improves emissions, but mostly at the expense of mobility since people wait longer for the bus. This measure also has the consequence of shifting a portion of the bus ridership to colectivos.

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