

**Sustainable Urban Mobility:  
Exploring the Role of the Built Environment**

by

**Pericles Christopher Zegras**

Master of Science in Transportation, Massachusetts Institute of Technology, 2001  
Master in City Planning, Massachusetts Institute of Technology, 2001  
Bachelor of Arts in Economics, Tufts University, 1990

Submitted to the Department of Urban Studies and Planning  
in Partial Fulfillment of the Requirements for the Degree of

**Doctor of Philosophy**

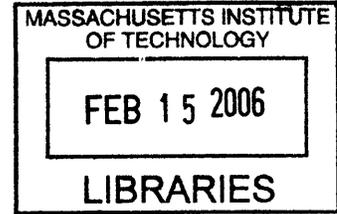
in

**Urban and Regional Planning**

at the

**Massachusetts Institute of Technology**

September, 2005



© 2005 Massachusetts Institute of Technology. All rights reserved.

**[ROTCH!]**

**Signature of Author:**

Department of Urban Studies and Planning  
28 July, 2005

**Certified by:**

Ralph Gakenheimer  
Professor of Urban Planning  
Thesis Supervisor

**Accepted by:**

Frank Levy  
Chair, The Ph.D. Committee

**Sustainable Urban Mobility:  
Exploring the Role of the Built Environment**

by

Pericles Christopher Zegras

Submitted to the Department of Urban Studies and Planning  
on 4 August, 2005 in Partial Fulfillment of the Requirements for the  
Degree of Doctor of Philosophy in Urban and Regional Planning

**ABSTRACT**

This dissertation examines the concept of sustainable mobility within an urban context. In essence, the research aims to answer the question, “What role does a city's built environment play, if any, in the sustainability of its mobility system?” To answer this question, I first derive an operational definition of sustainable mobility: *maintaining the capability to provide non-declining accessibility in time*. Providing non-declining accessibility depends on our ability to maintain net capital (natural, human-made, social) stocks, or, at least, the capability of these stocks to provide current levels of accessibility to future generations. In other words, we can think of a *more* sustainable mobility system as one that provides more welfare per unit of throughput, with welfare measured by accessibility and throughput measured by mobility. This is a *normative* framework. It can only indicate relative levels of sustainable mobility. Within a specific city, this framework can allow us to measure which parts of the city produce more sustainable mobility patterns.

To employ this framework, I utilize a utility-derived accessibility measure. The attractiveness of a utility-based accessibility metric comes from its basis in welfare economics, its ability to account for individual characteristics and preferences, and the possibility for its derivation from the random utility-based models (e.g., logit), which have a long tradition of use in transportation planning. Also, drawing from the large research base exploring the role of the built environment on transportation, I develop several models that assess the influence of the built environment on travel behavior, in particular, motor vehicle ownership and use. These models, combined, enable the exploration of sustainable mobility within a given city. I apply the framework to the city of Santiago de Chile, utilizing data from a 2001 household travel survey and a 2001 real estate cadastre, specifying a nested destination and mode choice model, and examining a subset of discretionary trips by seven different travel modes. Variations by income, gender, and modal availability are explored. I conclude with a discussion of the implications in the face of current urban growth patterns in Santiago.

Thesis Supervisor: Ralph Gakenheimer

Title: Professor of Urban Planning, Massachusetts Institute of Technology

## ACKNOWLEDGEMENTS

This dissertation finds its roots in my first view of the Andean mountains, which I enjoyed on an early Spring morning, arriving in downtown Santiago in September 1991. My experiences living, working, and observing the city's oddly chaotic order at that time inspired an interest – that turned into a career – in issues involving transportation, urban development, society, and nature. Over the past 15 years, I have had the great fortune of being able to watch Santiago's rapid evolution, an evolution – evidenced in the transformation of the bus system, the sprouting of “Sanhattan,” the rapid expansion into the foothills, etc. – that leaves me somewhat torn about the city's current path. In any case, I dedicate this dissertation to all *Santiaguinos* of present and future generations and hope that my work might provide even a little support in helping them create a “good” (in the Lynchian sense) city.

Closer to home, I dedicate this dissertation to Athena, whose love, support and incredible patience during this past year have convinced me she is an angel. Te quiero, te adoro, eternamente.

I simply could not have asked for a better dissertation committee. Ralph Gakenheimer has been mentor, teacher, friend and overall fount of wisdom, calm, guidance and humor over the past seven years. I am truly honored to have had the chance to learn from him, work with him, and know him. Joseph Sussman has also been a great source of knowledge, inspiration and motivation for me since I first arrived at MIT and I greatly appreciate his support. Finally, I am sincerely indebted to William Anderson for his agreeing to serve on my Committee; he has been amazingly generous, patient, insightful and encouraging throughout this process. Together, these three people provided the perfect combination of vision, strategy, knowledge, and motivation to get me where I am. I can only say thank you.

In Chile, I thank Henry Malbrán Rojas, the Secretario Ejecutivo of SECTRA, for providing access to the origin-destination survey data, the real estate cadastre, and additional data upon which much of the analysis in this dissertation is based. Henry has been a great friend over the years and I would not be writing this right now if it were not for him. Also at SECTRA, I thank Alan Thomas for his kind friendship; both Alan and Esteban Godoy were extremely generous with their time in providing data and other information and answering too many questions from me. At MINVU, I thank Sergio Leon, for providing access to relevant data, and Pedro Muñoz, for providing relevant GIS files and for several very useful conversations. At the Pontificia Universidad Católica de Chile, I thank Juan de Dios Ortúzar for his advice on model development and for answering many questions about the OD survey.

Many other people in Chile provided help and friendship over the years. I especially want to thank Edmundo Rojas, Daniel Castillo, Juan Carlos Sáez, los Duharts, y el *Flaco*.

MIT and the Boston area more broadly has been a remarkable place to pursue this research. And the true value of the place comes from its people – people who always

seem to know the answer to a question and are willing to go out of their way to help. I have benefited enormously from them. In particular, I would like to thank: Xiongjiu Liao for his help with the GIS data processing underpinning the spatial analysis and, in general, for being an excellent teacher of GIS skills; Jinhua Zhao for several useful theoretical conversations and for reviewing early modeling results with me; Jiawen Yang, who always seemed to be there to help come up with a database query and engage in spirited discussions regarding several relevant concepts; Charisma Choudhury, an excellent tutor in my early use of Biogeme; Mikel Murga, who provided absolutely critical help in developing network level of service measures using TransCAD; Cristian Angelo Guevara, for many useful discussions on model specification; Joseph Ferreira and Rhonda Ryznar, both of whom gave me much of their time in very helpful conversations; Thomas Oles, for an illuminating conversation on modernism and post-modernism planning ideas; Carlo Ratti, for several helpful discussions relating to urban morphology; Joan Walker, for taking the time to talk through some of my modeling issues and patiently sharing her knowledge with me; Judy Layzer for her invaluable comments on my original proposal and helpful advice on the dissertation process; Karen Polenske for great support and strategic advice at several key moments; Larry Vale, for his encouragement and understanding throughout this process; and, many of my fellow Ph.D students (including Liz Reynolds, Apiwat Ratanawaraha, Ryan Tam, La Tonya Green) for commiserating throughout this arduous journey .

The linear regression models in this dissertation were estimated with SPSS (version 12.0) and Eviews4 (Quantitative Micro Software). The discrete choice models were estimated with Biogeme (Version 1.0), freeware graciously provided by Michel Bierlaire, of the Ecole Polytechnique Fédérale de Lausanne. Michel also provided many useful modeling suggestions and help. Biogeme's default optimization algorithm, BIO, was used, as well as, in some cases, DONLP2. For use of the latter algorithm, I acknowledge its author, P. Spellucci and its availability at: <http://www.netlib.org/opt/donlp2/>.

This dissertation would not have been possible without the generous financial support of the Massachusetts Institute of Technology, through a Presidential Fellowship, the U.S. Department of Transportation, through an Eisenhower Graduate Transportation Fellowship, and the Lincoln Institute of Land Policy, through a Dissertation Fellowship. Additional support for data analysis came from the Alliance for Global Sustainability (AGS), through the project, "Designing, Implementing and Measuring Sustainable Urban Development."

Finally, I want to thank my family, to whom I have been something of a "ghost" son, grandson, brother, uncle, nephew and cousin over the past year. I love you all.

## TABLE OF CONTENTS

I	Introduction.....	10
I.1	Basic Research Questions and Research Approach .....	12
I.2	Structure of the Dissertation .....	12
II	Sustainability and Sustainable Transport: Setting The Stage .....	13
II.1	Sustainability and Sustainable Development.....	13
II.2	Defining & Measuring Sustainable Development .....	14
II.2.1	Sustainability Indicators.....	15
II.2.2	The Complexity of the Concept .....	17
II.3	Urban Sustainability or Sustainable Urban Development.....	18
II.3.1	City Planning, City Design, and Sustainability .....	20
II.4	Sustainable Transportation & Sustainable Urban Mobility .....	24
II.4.1	Sustainable Transportation: Briefly Tracing the Evolution of a Concept .....	24
II.4.2	Sustainable Transport: Examples of Definitions and Principles .....	26
II.4.3	System Complexity and Boundaries .....	28
II.4.4	Sustainable Transportation Indicators .....	30
II.4.5	Sustainable Transportation Indicators .....	32
II.5	Conclusions.....	35
III	Accessibility & Mobility: Towards an Operational Definition and Metric for Sustainable Mobility.....	37
III.1	Sustainable Mobility: Defining and Measuring .....	37
III.1.1	Sustainable Mobility: An Operational Definition .....	38
III.1.2	Sustainable Mobility: An Indicator .....	40
III.2	Accessibility.....	43
III.2.1	Utility-Based Measures .....	45
III.2.2	Accessibility and Travel Demand: An Indicator or Variable? .....	51
III.2.3	Accessibility as an Indicator for Sustainable Mobility.....	52
III.3	Accessibility, Travel Demand, and Mobility .....	54
III.4	Conclusions.....	55
IV	The Built Environment, Mobility & Accessibility .....	56
IV.1	Introduction.....	56
IV.2	Scales of Effects and Means of Influence .....	58
IV.3	Analytical Precedents.....	63
IV.3.1	The Metropolitan (Macro) Scale: The Effects of Urban Structure.....	66
IV.3.2	Intra-metropolitan (Meso-scale) Scale: The Effects of Urban Form.....	69
IV.3.3	The Neighborhood (Micro) Scale: The Influence of Urban Design.....	73
IV.4	Conclusions.....	80
V	Measuring Urban Form, Design and Neighborhoods.....	83
V.1	Challenges to Measurement .....	83
V.1.1	The Modifiable Areal Unit Problem .....	83
V.2	Analyzing Effects: Built Environment Measures or Neighborhood Units?.....	86
V.2.1	Built Environment Measures.....	87
V.2.2	“Neighborhood”-Oriented Approaches .....	90
V.3	Conclusions.....	93
VI	Santiago in Context .....	95
VI.1	Internationally .....	95
VI.1.1	Regionally .....	101
VI.1.2	Santiago in the National Setting.....	106
VI.2	Conclusion .....	108

VII	Exploring a Metropolis: Planning, People, Forms and Designs.....	110
VII.1	Santiago de la Nueva Extremadura.....	110
VII.1.1	Modern Planning Tensions.....	112
VII.2	The Making of a Middle Class City .....	115
VII.2.1	Spatial Socio-economic Segregation.....	116
VII.3	The City Structure, Form, Design.....	121
VII.3.1	A Note on Data Sources and Data Preparation .....	121
VII.3.2	Macro Scale: Urban Structure and Evolution.....	122
VII.3.3	Meso Scale: Urban Form.....	126
VII.3.4	The Micro Scale: A Glimpse at Urban Design.....	134
VII.4	Exploring <i>Physical</i> Neighborhoods .....	138
VII.5	Conclusions .....	141
VIII	A Metropolis on the Move: Santiago’s Basic Travel Characteristics & Impacts.....	142
VIII.1	A Note on Data Sources .....	142
VIII.2	Basic Travel Characteristics .....	144
VIII.2.1	Trip Rates & Purposes .....	145
VIII.2.2	Average Travel Times and Distances .....	147
VIII.2.3	Mode Shares.....	150
VIII.2.4	Total Travel Distances & Mobility Throughput .....	152
VIII.3	Transportation’s Environmental and Other Effects .....	154
VIII.4	Conclusions .....	156
IX	Pulling the Pieces Together: The Built Environment & Sustainable Mobility .....	158
IX.1	Precedents .....	158
IX.2	Household Motor Vehicle Choice.....	160
IX.2.1	Motor Vehicle Ownership Patterns and Evolution.....	160
IX.2.2	A Note on Accessibility in the Motor Vehicle Choice Model .....	161
IX.2.3	Model Specification, Estimation, Results .....	162
IX.2.4	Discussion .....	165
IX.3	Vehicle Use.....	166
IX.3.1	Model Specification and Estimation .....	167
IX.4	Mode Choice, Destination Choice and Accessibility.....	171
IX.4.1	Overview of Model Structure.....	171
IX.4.2	Trip Purpose Subset .....	172
IX.4.3	Lower Level Mode Choice.....	174
IX.4.4	Upper Level Destination Choice .....	178
IX.4.5	Alternative Model Structure.....	179
IX.5	Accessibility, Sustainable Mobility, and the Built Environment.....	183
IX.5.1	Basic Accessibility Levels for Visit and Recreation Trips.....	187
IX.5.2	Mapping the Sustainable Mobility “Trade-Off Space” .....	196
IX.6	Conclusions.....	202
X	Conclusions and Implications.....	205
X.1	Sustainable Mobility: The Theoretical Framework .....	205
X.1.1	Sustainable Mobility: An Operational Definition .....	206
X.2	Sustainable Mobility: Towards a Methods of Measurement in the Urban Setting ....	208
X.2.1	The Role of the Built Environment .....	209
X.3	Implications for Santiago .....	210
X.3.1	Santiago: <i>Quo Vadis?</i> .....	211
X.3.2	Primary Implications from Modeling.....	216
X.3.3	Accessibility and Sustainable Mobility .....	217
X.3.4	Policy Relevance of the Analytical Results.....	218
X.3.5	In Summary: Strengths, Shortcomings and Future Research .....	219

Appendix.....	222
References.....	231

## LIST OF FIGURES

Figure I-1. The Urban Transportation Cycle and Sustainability Challenge .....	11
Figure II-1. The Information Hierarchy through the Sustainable Indicator Prism .....	16
Figure II-2. World Demographic and Urbanization Projections .....	18
Figure II-3. Mapping Lynch’s “Good City” Performance Dimensions to The Capital Construct of Sustainability .....	23
Figure II-4. Stylized Representation of a Hypothetical Person’s Values Today as they Relate to Transportation and Sustainability and the Role of A Theoretical “Discount Rate” .....	29
Figure II-5. The Role of Indicators in the Transportation Planning Process.....	31
Figure III-1. “Building” on Capital: Accessibility and Sustainability.....	39
Figure III-2. Hypothetical Sustainable Mobility “Trade-Off” Space .....	43
Figure III-3. Basic Depiction of a Two Level Nested Logit Travel Decision.....	47
Figure IV-1. Hypothetical Urban Forms Tested in Simulation Models of Urban Form & Transport Energy Use in the 1970s.....	71
Figure V-1. What TAZ Do You Live In? TAZ Boundaries and Block-level Dwelling Unit Densities (Santiago).....	85
Figure VI-1. Santiago Relative to Select Industrialized Cities.....	100
Figure VI-2. Santiago Relative to Cities in Similar Income Range .....	100
Figure VI-3. Private Vehicle Use & Density: A Global Comparison (1990).....	101
Figure VI-4. Latin America’s Largest Cities and Their Population Growth.....	102
Figure VI-5. Santiago and Select Latin American Cities: Mobility Characteristics .....	105
Figure VI-6. Map of Chile’s Regions (right).....	106
Figure VI-7. Mode Share (Work Day) and Share of Households with No Motor Vehicle: Primary Chilean Cities.....	109
Figure VII-1. The Original Grid and Plaza de Armas .....	110
Figure VII-2. The “True” Making of A “Middle Class City”?.....	116
Figure VII-3. Average Household Income in Greater Santiago .....	117
Figure VII-4. Standardized Segregation Index by <i>Comuna</i> in Greater Santiago .....	119
Figure VII-5. <i>Comuna</i> Segregation Index: 2001 .....	120
Figure VII-6. <i>Comuna</i> Population 1970-2002.....	123
Figure VII-7. Average Annual Intercensal Population Growth Rates by <i>Comuna</i> .....	124
Figure VII-8. Evolution of Land Area and Population Density in Greater Santiago .....	125
Figure VII-9. Santiago’s Primary Transportation Infrastructure: 2001 .....	127
Figure VII-10. Commercial Activities and Malls in Greater Santiago: 2001.....	128
Figure VII-11. Industrial Activities (2001) and 1960 Zoning Plan .....	129
Figure VII-12. Concentration of Major Office Space .....	130
Figure VII-13. Proposed Sub-Centers in the 1960 Intercomunal Plan.....	131
Figure VII-14. Residential Form: Dwelling Unit Density, Floor-Area Ratio, Avg Size.....	132
Figure VII-15. Indicators of Urban Form: Parks, Sports and Plazas.....	133
Figure VII-16. A Patchwork of Santiago’s Block Morphology .....	135
Figure VII-17. The Diversity Index.....	136
Figure VII-18. The Potential Bias of the Dissimilarity Index .....	137
Figure VIII-1. Work Week Trip Rate by Income Category and Sector of the City .....	145
Figure VIII-2. Leisure and Shopping Trip Rates: Weekday, Weekends and “Composite” Household.....	146
Figure VIII-3. Average Reported Weekday Travel Times By Mode: 1991 vs. 2001 .....	148

Figure VIII-4. Greater Santiago’s Intra-urban Bus Routes (1999).....	150
Figure VIII-5. Weekday Metro Station Accesses & TAZ-Population Densities .....	151
Figure VIII-6. Mode Share for All Trips. Variation by Season and Weekday/Weekend.....	152
Figure IX-1. Example Depiction of the Nesting Structure in a Simple Destination and Mode Choice Process.....	172
Figure IX-2. Density of Households (Households per Hectare) by Basic Household Income Category.....	184
Figure IX-3. Social Accessibility Levels (Logsum): Female Adult (High, Medium, Low Incomes; left to right).....	185
Figure IX-4 . Recreational Accessibility (Logsum): Male (top) & Female (bottom) (High, Medium, Low Incomes; from left) .....	186
Figure IX-5. Relative Decline in Recreational Accessibility Due to Loss of Auto (left), Bike (center), Metro (right): Middle Income (top) and Lower Income (bottom) Female.....	189
Figure IX-6. Relative Decline in Recreation (left) and Social (right) Accessibility for Low Income (top) and Middle Income (bottom) Female: Loss of Bike .....	190
Figure IX-7. Average Relative Decline in Social (left) and Recreational (right) Accessibility: Female Loss of Automobile.....	191
Figure IX-8. Areas with Lowest Average Decline in Relative Social and Recreational Accessibility after Loss of Automobile: Female (left) and Male (right) .....	192
Figure IX-9. Close Up Views of Areas with Relative Automobile “Independence” for Social and Recreation Trips.....	193
Figure IX-10. Actual (left) and Predicted (right) Weighted PKT per Recreation Trip .....	199
Figure IX-11. Actual (left) and Predicted (right) Weighted PKT per Visit Trip.....	200
Figure IX-12. Accessibility-to-Weighted PKT Sustainable Mobility Ratio: For Social (left) and Recreation (right) Travel by a 35-Year Old Middle Income Female .....	201
Figure X-1. Chicago and Santiago: City and Regional Comparison.....	215
Figure X-2. Santiago’s “Park” City, “Front Yard” Cities, and “Marginal” City.....	216

## LIST OF TABLES

Table II-1. Hirt’s Juxtaposition of Modernism and Postmodernism in Planning.....	22
Table II-2. Indicators Used in the SPARTACUS project.....	35
Table III-1. Accessibility: Influencing Factors.....	37
Table III-2. “Functionings” & “Capabilities”: Mapping Sen’s Human Development Concepts to Accessibility and Mobility.....	38
Table III-3. Basic Categorization of Accessibility Measures.....	44
Table IV-1. The Built Environment and Travel: Scales of Analysis and Influence.....	59
Table IV-2. Activity Classification Based on Time and Space Requirements.....	62
Table IV-3. The Influence of the Built Environment on Transport: Example Approaches by Scale and Technique of Analysis .....	65
Table IV-4. Micro-Level Built Environment (and Socio-Demographic Control) Variables Influencing Auto Ownership and Auto and Transit Use in Toronto.....	74
Table IV-5. “Typical” Elasticities of Travel with Respect to Urban Form and Design .....	75
Table V-1 Spatial Units of Analysis in Several Recent Studies.....	84
Table V-2. Micro-Level Built Environment Measures in Recent Relevant Studies .....	88
Table V-3. Basic Characteristics of Development Types in Toronto, Ontario.....	90
Table V-4. “Neighborhood Themes” in Orange County, California.....	92
Table VI-1. A Principal Components Approach to Typologizing City Transport .....	96
Table VI-2. Santiago: Basic Mobility Characteristics Relative to Select Industrialized World Cities.....	97

Table VI-3. Santiago. Basic Mobility Characteristics Relative to Select “Peer Developing” Cities .....	98
Table VI-4. Santiago and Her <i>Hermanas Latinas</i> : The Large Latin American Cities .....	104
Table VI-5. Santiago and Select Latin American Cities: Mobility Characteristics .....	105
Table VI-6. Percentage of Chilean Households Living in Poverty, By Region .....	106
Table VI-7. Chile’s Principal Cities, Demographics, Socioeconomics .....	108
Table VII-1. Periods of Growth and Forces of Relevance in Santiago de Chile: From Founding to Present .....	114
Table VII-2. Greater Santiago: Households by Income Category .....	115
Table VII-3. Typologies of Santiago’s Residential Neighborhood Developments .....	138
Table VII-4. Principal Component Analysis Pattern Matrix .....	140
Table VIII-1. Evolution of Basic Socioeconomic & Travel Characteristics .....	144
Table VIII-2. Trips with Origins or Destinations Outside the Metropolitan Area: by Primary Purpose and by Season .....	147
Table VIII-3. Average Trip Times, Rates and Distances .....	149
Table VIII-4. Travel Times, Distances and Modes by Income Strata: Work Day .....	149
Table VIII-5. Metro: Primary Mode of Access/Egress (2001).....	151
Table VIII-6. Total Annual Passenger Kilometers Traveled (PKT) (in millions) by Different Modes .....	153
Table VIII-7. Annual Pollutant Emissions Inventory by Source (% of Total): 2000.....	154
Table VIII-8. Reported Traffic Incidents and Deaths and Injuries in Santiago.....	155
Table IX-1. Number of Four-Wheel Motor Vehicles and Driver’s Licenses per HH .....	160
Table IX-2. Multinomial Logit Model of Household Motor Vehicle Choice .....	163
Table IX-3. Relative Importance (D) of the Independent Variables to the Household Vehicle Choice Probabilities.....	164
Table IX-4. Auto Driver Trips Made by Persons from Households with No Vehicle .....	167
Table IX-5. Estimated Intra-Urban Auto Use Per Vehicle in Santiago (2001).....	167
Table IX-6. OLS Estimate of Household Total Automobile Use.....	169
Table IX-7. Best Mode Choice Model Results for Visit Trips.....	176
Table IX-8. Best Mode Choice Model Results for Recreation Trips .....	177
Table IX-9. Destination Choice for Visit Trips: Destination as the Upper Level Nest.....	179
Table IX-10. Destination Choice for Recreation Trips: Destination as the Upper Level Nest ..	179
Table IX-11. Visit Trips Destination Choice Model Results: Destination as Lower Level Nest	180
Table IX-12. Recreation Trips Destination Choice Model Results: Destination as Lower Level Nest.....	181
Table IX-13. Best Mode Choice Model Results for Visit Trips: Mode Choice as Upper Level Nest.....	182
Table IX-14. Best Mode Choice Model Results for Recreation Trips: Mode Choice as Upper Level Nest.....	183
Table IX-15. Basic Characteristics Used to Represent Adult Accessibility.....	183
Table IX-16. OLS Model of Weighted PKT for Visit Trips .....	197
Table IX-17. OLS Model of Weighted PKT for Recreation Trips.....	198
Table X-1. Chicago (1956) and Santiago (2001): Basic Indicators.....	212

# I

## INTRODUCTION

*O to live in a small gone Horatian suburb  
lost in its melancholy stream of traffic –  
- R. Lowell, 1973*

Sustainability, sustainable development, sustainable... These words have plowed themselves into mainstream development dialogue and literature, if not entirely into popular jargon. One does not need to look far to find references to sustainable housing, consumption, forestry, agriculture, etc. Some of these sectors lend themselves naturally to the sustainability concept and, indeed, essentially formed the basis for modern ideas about sustainable development. The word sustainability has, in some senses, proved useful in itself, by at least making more explicit the need to balance environmental, social and economic development objectives. But, at the same time, the increasing ubiquity of the use of the word runs the risk of watering down its true meaning. When sustainability becomes associated with more and more, it might actually start to mean less and less.

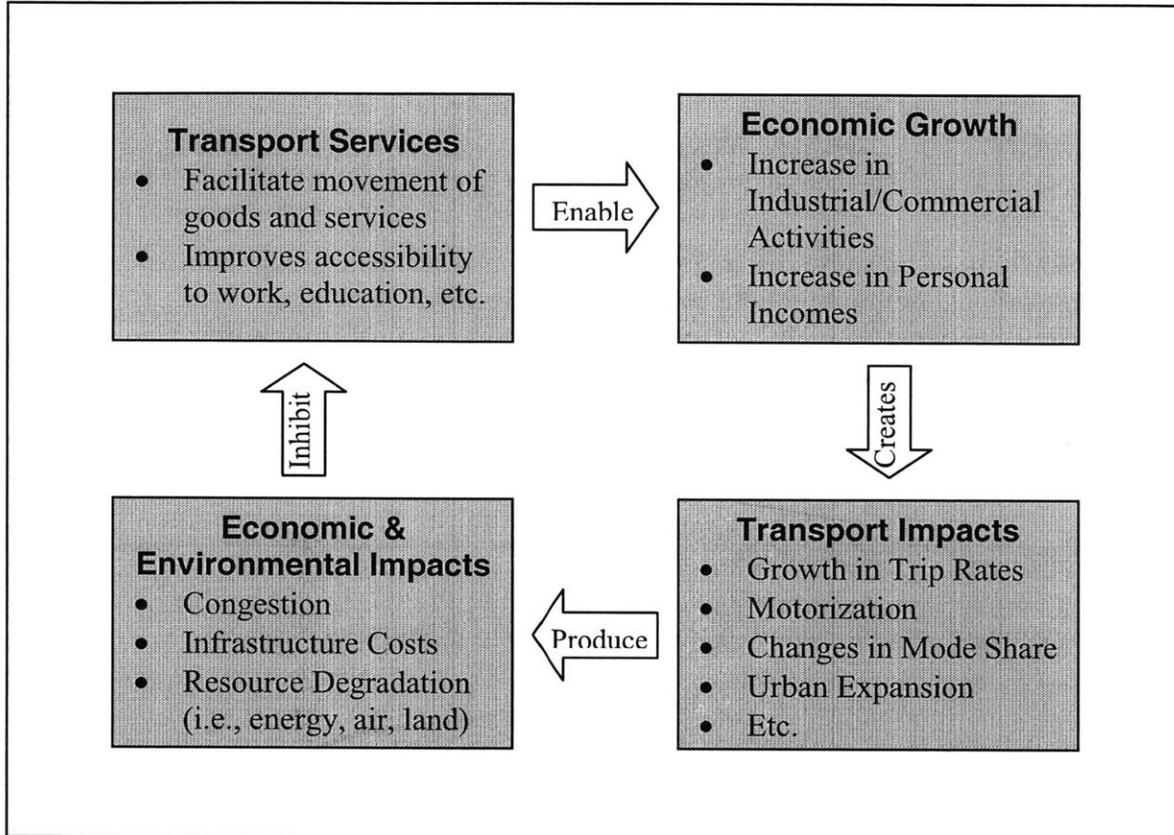
In the transportation sector, the use of the word sustainable dates at least to the late 1980s (Replogle, 1987) – when sustainable development broke into mainstream development rhetoric – and was progressively mainstreamed during the 1990s, via governments, international agencies, the private sector, NGOs, etc. Some of the work has been in the form of policy guidance (e.g., World Bank, 1996), efforts to clarify meanings and principles (e.g., CST, 2002), world-wide assessments of transportation conditions (e.g., WBCSD, 2001), the development of indicators (e.g., Lee et al., 2003), and the derivation of specific methodologies for urban land use and transport planning (e.g., Mincken et al., 2003).

Not surprisingly, a considerable amount of the sustainable mobility research and analyses focuses on urban transportation. The metropolitan focus is logical. The world continues urbanizing apace; in fact, the UN (2001) projects that by 2030 an additional 2 billion people will be added to the world's urban areas. In this context, a focus on the developing world becomes important – virtually *all* of the world's net urban population growth will occur in developing cities. This growth poses considerable planning and management challenges for the variety of urban sectors, such as housing, sanitation, water, and transportation. A basic, fundamental requirement for developing countries is that they develop – in other words, we must hope that urbanization will be accompanied by economic development. Transportation clearly plays a major role in facilitating this development. At the same time, development further fuels demand for transportation, which, in turn, creates economic, social and environmental impacts (see Figure I-1).

In short, ongoing urbanization and economic growth mean that more people will be making more trips across longer distances in more cities across the globe. In the face of this growth, urban transportation systems must balance two basic needs. On the one hand, we need transportation to continue to contribute to economic development and human welfare. On the other hand, we need to mitigate transportation's negative effects, both

current, as exhibited by pollution and accidents, as well as future, seen through contribution to potential climate change and potential exhaustion of non-renewable resources. In other words, can our urban transportation systems be made more sustainable?

**Figure I-1. The Urban Transportation Cycle and Sustainability Challenge**



Source: Derived from Zegras, 1998b.

Any suitable strategy for pursuing sustainable urban mobility will inevitably require a package of different options. Vehicle technological options, for example, can reduce pollutants and improve safety, while infrastructure options can improve system reliability and speed. In fact, the technological “fix” may well “come to the rescue” for some of the most pressing issues, although considerable uncertainties remain about the timeliness of technology adoption (see, e.g., Heywood et al, 2003). Among the available options, the built environment – the physical characteristics that make up our human settlements – will almost certainly have to play some role. After all, the built environment provides the underlying context within which human activities take place. The idea of using the built environment as an explicit strategy to improve transportation conditions is not new and today finds mention – at a minimum – in most assessments of urban transport sustainability. In some cases, it is regarded as critical to long-term sustainability, if not solely for transportation reasons, then for other motivating factors (such as preservation of open space, etc.).

## **I.1 Basic Research Questions and Research Approach**

For the rapidly growing developing world cities, land use may have a particularly important role to play, since a population growth rate of just 2.5% per year – still common in many developing cities – means that an urban area will double its population in less than 30 years. Such growth rates will essentially lock in urban structures – and their underlying travel behaviors – for generations. This reality leads naturally to the question: what role does the built environment play in the sustainability of urban mobility in the developing city context?

In an attempt to answer this basic question, this dissertation follows multiple steps, each of which aims to answer a number of relevant “sub”-questions:

1. What do we mean by sustainable mobility and sustainable urban mobility? Can an operational definition of the concept be derived?
2. How can we effectively measure the concept of sustainable mobility? Can an effective indicator, or indicators, be derived? How do these indicators relate to existing transportation indicators and the idea of “performance-based” transportation planning?
3. What role does the built environment play in travel behavior, what does the existing evidence tell us and what are the problems with and challenges to the various analytical techniques used?
4. What role, if any, then, does the built environment play in determining sustainable urban mobility (as measured by the answer to question 2, above)?

In answering these questions, I look at a specific city, Santiago de Chile, and a specific aspect of that city’s transportation system, the passenger transportation system. While such a subsystem focus will naturally force some artificial boundaries – e.g., isolating the city from the larger economic system, separating freight from passenger mobility – this subsystem focus allows for a tractable approach to answering the basic research question.

## **I.2 Structure of the Dissertation**

Following this Introduction, Chapter II provides a background to the sustainable mobility concept, tracing its origins and evolution, highlighting the multiple relevant definitions and outlining some of the efforts to measure the concept. Chapter III derives an operational definition of sustainable mobility, proposes a metric for measurement (indicator), and relates this metric to other relevant indicators. To understand the potential influence of the built environment on travel behavior, Chapter IV reviews the relevant research, proposing an analytic framework for understanding the various approaches, while Chapter V focuses specifically on the different ways of measuring the built environment. Chapters VI through VIII introduce the empirical case, Santiago de Chile, situating the city within the international and national settings, describing its planning influences and primary physical and socio-economic characteristics, and presenting the basic mobility patterns of its residents, including their evolution in time. Chapter IX presents the main analysis, including models of vehicle ownership and use and measures of sustainable mobility and the role of the city’s built environment. Finally, Chapter X discusses the major policy and research implications of the work.

## II

# SUSTAINABILITY AND SUSTAINABLE TRANSPORT: SETTING THE STAGE

### II.1 Sustainability and Sustainable Development

The word sustainability has become almost trite. The concept, itself, can be traced far back in the fields of economics and natural resources, relating to the capacity of natural stocks (e.g., of fish, forests, soil), the Malthusian concept of resource exhaustion due to population growth, and fundamental economic principles (e.g., Hicks) on the relationship between consumption and wealth. By at least the late 1960s, one can find prominent ethicists and economists focusing on relevant issues. Baumol (1968), for example, writing on social discount rates, highlights the special attention necessary for possible “irreversibilities,” such as “if we poison our soil...[or] destroy the Grand Canyon” (p.802).<sup>1</sup> Rawls (1971), in his landmark *A Theory of Justice*, suggests that we have a natural inclination to promote the well-being of our descendants.

The prevailing modern usage of the word sustainability finds its recent roots in the environmental movement, for example, the 1972 UN Conference on the Human Environment and Meadows et al’s (1972) *Limits to Growth*, which helped to push environmental concerns onto the global agenda. A follow-up to *Limits to Growth*, *Alternatives To Growth* (Meadows, 1977) includes papers from a wide range of disciplines, presented at a conference aiming to chart paths to potential “sustainable futures,” which are associated with a “steady state” economy and a “just” society. Rees (1997) credits the World Conservation Strategy of 1980 with the first explicit use of the term “sustainable development.” By the late 1980s the idea of (environmental) sustainability became formally integrated into mainstream development concerns with the release of the now well-known Brundtland Report (WCED, 1987), which formalized the concept of sustainable development, recognizing the fundamental need to live within the earth’s means and the implications for passing on the same (or greater) amount of total resources to future generations.<sup>2</sup> By 1992, sustainable development hits center stage, when the United Nations convened the Conference on Environment and Development in Rio de Janeiro (often referred to as the “Earth Summit”) – organized around the principal themes “environment and sustainable development.”

---

<sup>1</sup> Interestingly, however, Baumol recommends subsidized investments for such protections, not a lower general discount rate; beyond such “irreversibilities,” Baumol suggests: “the future can be left to take care of itself” (p. 801).

<sup>2</sup> While not rigorous and by no means comprehensive, a database search on the topics (sustainability, sustainable development or sustainable) in the ISI “Web of Science” citation index (which includes journal articles from Science Citation Index, Social Sciences Citation Index, and the Arts & Humanities Citation Index) is somewhat indicative of the “growth” of interest in sustainability. The number of articles cited including at least one of those topics returns the following number of citations (in 7 year periods; 1973 being the earliest period available, 1980 marking the supposed first appearance of “sustainable development,” 1988 being the first year post-Brundtland): 1973-1980: 42; 1981-1988: 226; 1989-1996: 5,802; 1997-2004: 18,583. Note, that this does not control for number of journals searched, nor the appearance of the term outside of the specific context implied here.

The idea of sustainable development then begins to take on a broader perspective than simply one of environmental concerns and by the 1990s the “three dimensions” of sustainability come to the fore: environmental, economic, and social (or equity) – the so-called three E’s of sustainability. Some have extended the concept to include at least another dimension, the political or institutional dimension, sometimes as an overarching umbrella or underlying foundation to the sustainability concept. There are some indications that the idea of sustainability has become something of a catch-all term, which means everything and, thus, really nothing. By extending sustainability or sustainable development to include all aspects of life and life-systems, we run the risk of having it simply slip out of our grasp as a useful construct. As Keiner et al (2004, p. 13) note: “these terms [sustainability and sustainable development] are arbitrary and user-defined, and have lost their clear meaning.”

In a rigorous interpretation, sustainability can be seen as a strictly scientific construct, related to, for example, carrying capacities, biological processes and ecosystem functioning. Can the system sustain itself in time? In reality, however, sustainability becomes a heavily value-laden term and concept – an inevitability given its filtering through the human/social system. In fact, it is indicative that some of the first considerations of the implications of the sustainability idea can be found in religious (e.g., Pitcher, 1977) or ethics (e.g., Perelman, 1980) journals. Some (e.g., Crilly et al, 1999) go so far as to explicitly call sustainability a “political” and not “technical” issue. Ultimately, sustainability depends on our values: how do we value future generations and what we leave to them (related to, e.g., discount rates)? How do we value “non-economic” resources? How do we value the distribution of resources among current generations? Is sustainability really a new concept, or simply new language for various interpretations of a good society that have existed throughout time?

## **II.2 Defining & Measuring Sustainable Development**

If the goal is to “achieve” sustainable development, or at least move in a sustainable “direction,” how, exactly, do we know if we are making progress? Clearly, we need some form of an operational definition, to provide specific guidance on how the concept will be measured (Meier and Brudney, 2002). For example, we can establish an operational definition for meeting air quality standards for fine particulate matter (PM<sub>2.5</sub>) as: “Areas will be in compliance with the annual PM<sub>2.5</sub> standard when the 3-year average of the annual arithmetic mean PM<sub>2.5</sub> concentrations is less than or equal to 15 µg/m<sup>3</sup>.” In this case, the operational definition establishes how the concept, air quality compliance (for fine particulates), will be measured: through mean PM<sub>2.5</sub> concentrations. In other words, we would use mean PM<sub>2.5</sub> concentrations as an *indicator* of compliance with air quality standards.

Regarding sustainable development, probably the most oft-cited definition comes from the Brundtland Report: “to ensure that [development] meets the needs of the present without compromising the ability of future generations to meet their own needs.” Rather than an operational definition of sustainability the Brundtland definition offers more a general statement of principles. Whether or not the principles implied in the Brundtland

definition – intergenerational equity and use of resources – can be effectively operationalized remains to be seen. The challenge becomes complicated when sustainability is viewed to encompass its multiple dimensions (equity, environment, economy, institutions, etc.).

The economists' perspective offers one tractable approach to arrive at an “operational definition” of the sustainability concept. If we simply define sustainability as the capability to “maintain the capacity to provide non-declining well-being over time” (Neumayer, 2003a)<sup>3</sup>, then we can utilize the economist's perspective of maintaining the value of total capital, including human, natural, social, and manufactured capital. Indeed, by the mid-1990s, the World Bank which was already claiming that it would only fund projects that were “sustainable in *economic, environmental, and social* terms (Serageldin, 1996, p. 2 [emphasis in original]) and, ostensibly, was defining sustainable development as a process by which current generations pass on as much, or more, capital *per capita* to future generations, with capital being defined as human-made, natural, social, and human (Serageldin, 1996). While intuitively attractive, this definitional approach still clearly suffers from measurement challenges including, but not limited to, issues of how to measure the social capital “stock.” Furthermore, even with the capital-based definitional direction of sustainability, different conceptual paradigms exist, particularly between two extreme positions relating to the substitutability of capital, which have been called “weak” sustainability and “strong” sustainability. Basically, weak sustainability considers that natural capital can be substituted for by other forms of capital, while strong sustainability rejects such substitutability (Neumayer 2003b; Kain, 2003).

## II.2.1 Sustainability Indicators<sup>4</sup>

As no single agreed-upon operational definition of sustainability or sustainable development exists, neither does any single means of measurement (i.e., indicators or performance measures). In fact, the plethora of sustainability definitions, initiatives, and projects seems matched by the number of efforts to “measure” sustainability. These range from macro-level, consolidated measures – typically some form of index – to multiple indicator frameworks, which often will aim to develop specific indicators in each of the sustainability “dimensions.” A hierarchical perspective, suggested by the “sustainable indicator prism” (see Figure II-1), helps to understand the relationship, in theory anyway, between data, indicators, indices and the ultimate goal of measuring the concept. In brief, raw data feeds the development of indicators, each of which might represent one of the sustainability dimensions (or capital stocks). These indicators, in turn, can be combined into indexes or a single index which, ostensibly, offer a comprehensive measure of progress towards the goal (sustainability or sustainable development).

Neumayer (2003a) provides a brief history of the development of sustainability indexes – from early efforts such as the Measure of Economic Welfare (MEW), the Index of

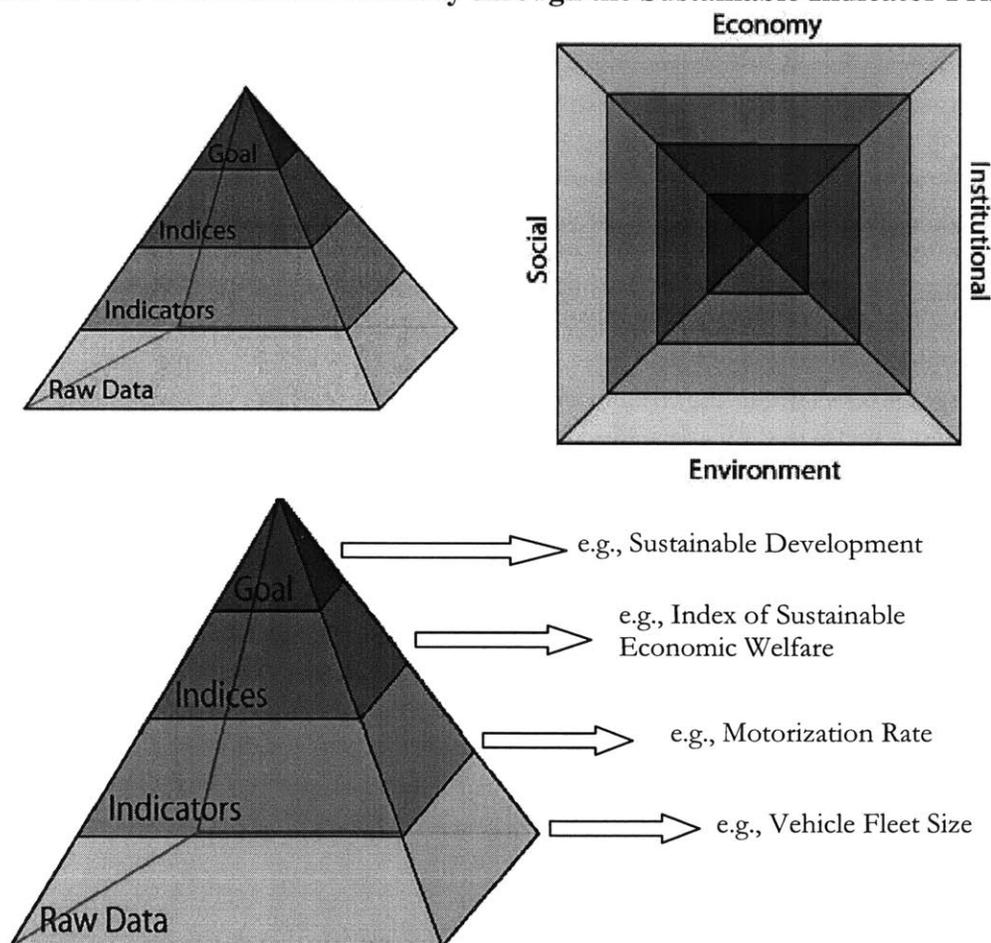
---

<sup>3</sup> Neumayer (2003b, p. 7) also offers the more technically rigorous, but slightly more awkward definition of sustainable development as not decreasing “the capacity to provide non-declining per capita utility for infinity.”

<sup>4</sup> It is well beyond the scope of this dissertation to provide a detailed overview of the range of issues related to sustainability indicators. Several recent reviews exist; see, e.g., Bossel (1999); Zegras et al (2004).

Sustainable Economic Welfare (ISEW) towards his own proposed measure which combines the UN’s Human Development Index (HDI) with World Bank estimates of “adjusted” or “genuine” savings (e.g., Hamilton and Clemens, 1999; World Bank, 2003b). Neumayer’s metric aims to show the degree to which a society achieves current well-being (measured via the HDI) at the expense of total capital stock, as measured by genuine savings, which attempts to measure capital in terms of investments in and depletions of various capital forms). Indexes derived in this way represent the “weak sustainability” perspective – i.e., assuming that depletion of natural capital can be compensated for (substituted by) another form of capital. A sustainability index which could be said to fall in the “strong sustainability” camp stock would be the “ecological footprint.” The footprint attempts to measure consumption and waste production and convert the resulting resource flows into an estimate of the biologically productive area needed to provide these functions (Wackernagel and Rees, 1996).

**Figure II-1. The Information Hierarchy through the Sustainable Indicator Prism**



Source: Zegras et al, 2004.

Looking towards the base of the prism, one naturally will find the multiple-indicator initiatives. The United Nations Division of Sustainable Development provides an example of national-level indicators, proposing a framework that includes 58 different indicators, representing various themes and sub-themes in four different dimensions of

sustainable development (social, environmental, economic, institutional (see UN DSD, 2004).

In attempting to measure sustainability, several challenges exist. A principal one comes from data availability, such as lack of information on, for example, genuine savings rates (even assuming those as an adequate measure of capital maintenance). Additional related challenges stem from the fact that data and related information will often come from political/administrative units that will rarely, if ever, match the functional range of relevant ecosystems (see, e.g., Gustavson et al, 1999). Furthermore, the inherent complexity of and feedback within the relevant socio-economic and natural systems and subsystems of interest raise the critical question of whether indicators can be developed which not only capture a picture of the system in time but that also can track changes in time and relevant system interactions (e.g., Hodge et al, 1999). This issue relates directly to a further challenge: developing indicators that can be effectively integrated in a “projective perspective” – in other words, suited for predicting future conditions (Gustavson et al, 1999).

### **II.2.2 The Complexity of the Concept**

The previous points remind us that we cannot ignore the complexity of the sustainability concept, however we choose to ultimately define it. In attempting to operationalize the idea of sustainability, we are dealing with systems that – as Innes and Booher (1999, p. 149) note – are “adaptive and self-organizing, with [their] components free to co-evolve in response to changes in each other and, as a whole, changing in response to external conditions.” We are looking at systems that are inherently complex, undergoing continuous transformations and adaptations, with feedback and learning, non-linear reactions, and randomness (e.g., Innes and Booher, 1999). Sussman (1999) uses the term CLIOS (for Complex, Large-scale, Integrated, Open Systems) to refer to such systems, which are characterized by: inter-related units, for which we have imperfect knowledge about the relationships; large, pervasive and, enduring impacts; integrated sub-systems, coupled through feedback loops; and open-ness, including social, political and economic aspects. Applying the CLIOS construct (see, e.g., Sussman and Dodder, 2002), particularly its structural representation, evokes a similar analytical framework and technique for representing and assessing dynamic complexity: system dynamics, a systems thinking and modeling technique. As noted by Sterman (1999), dynamic complexity arises because systems are: dynamic, tightly coupled, governed by feedback, non-linear, history-dependent, self-organizing, adaptive, counter-intuitive, policy resistant, and characterized by trade-offs. Recognizable by its characteristic “stock” and “flow” representation, system dynamics techniques are not new to the sustainability issue; in fact, *Limits to Growth* (Meadows et al, 1972), a book popularly credited with raising the notion of sustainable growth (as mentioned in Section II.1), was based on system dynamics modeling, the World3 model. A major problem with the *Limits to Growth* analysis was the failure to consider relevant economic mechanisms (e.g., price responses to relative scarcity) and technological progress.

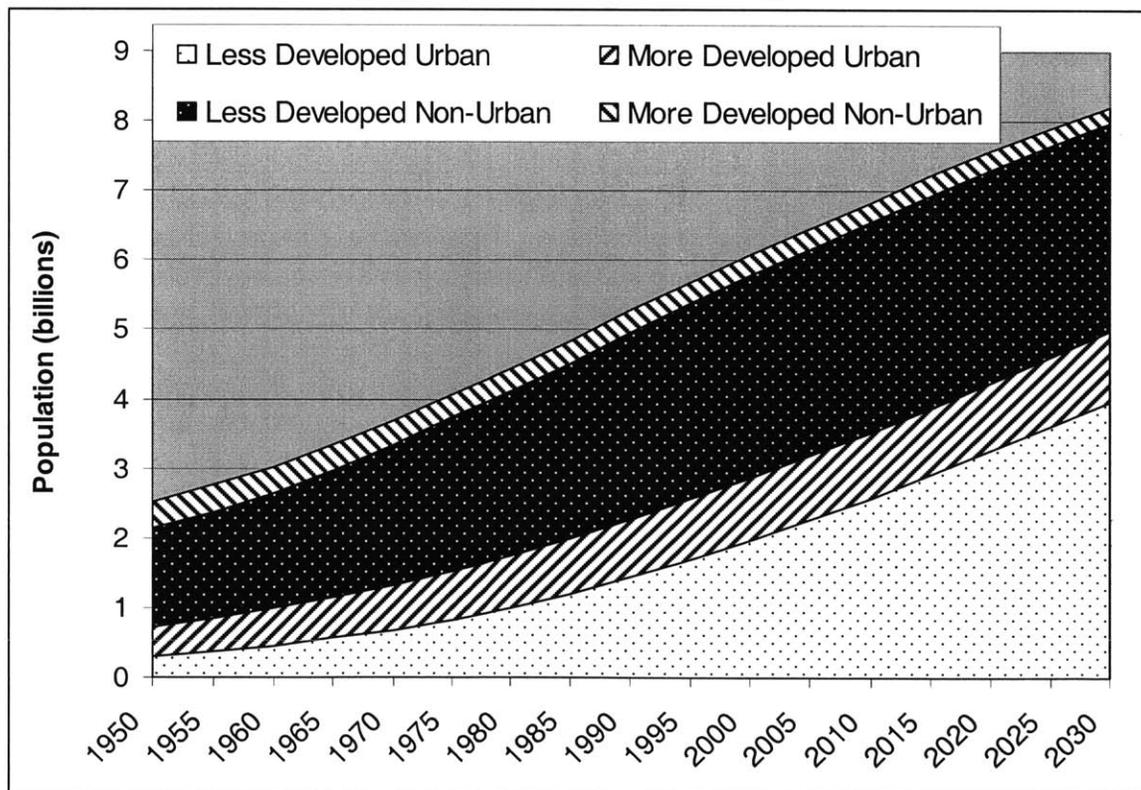
Ultimately, even when recognizing the complexity of the concept, we will do well to differentiate between sustainability – a concept, a vision, objectives towards which we

hope to move – and sustainable development, the process that moves us towards sustainability.

### II.3 Urban Sustainability or Sustainable Urban Development

The world continues to urbanize or, perhaps, more accurately stated, “metropolitan-ize” – in other words, while cities around the world continue to grow, the process is not *city- or urban-formation*, per se, but rather the agglomeration of urban, suburban and exurban *metropolitan* areas. The developed world is already largely urban and the United Nations projects that in the “more-developed” regions of the world nearly all net population growth will take place in urban areas (at an average annual rate of approximately 1.1%). In the “less-developed” regions, still less urbanized than the industrialized world, urbanization will continue apace, at an average annual rate of 3.1%. By 2030, the developing world’s urban population will *double*, representing 95% of net global population growth, or 1.94 billion additional people. To put this in perspective, during the latter half of the 20<sup>th</sup> Century, the developed world urban population doubled, adding “just” one-half billion people. If the world reaches the projected 8 billion plus inhabitants by 2030, just about 5 billion will live in metropolitan areas (see Figure II-2). In Latin American and the Caribbean and in Asia, the urbanization rates will continue to be strong: at an estimated 2.7% and 3%, respectively.

**Figure II-2. World Demographic and Urbanization Projections**



Source: UN, 2004.

With the ongoing, indeed intensifying, urbanization underway around the world – and accompanying environmental and social challenges – the sustainability concept was

quickly adapted to the urban context. Both the “construction” and “use” of cities have clear sustainability implications. Again, one can find immediate precedents of the “sustainable city” concept through concerns related to urban form and energy use – the depletable resource most often on the minds of city planners and policymakers in the early 1970s.<sup>5</sup> As early as 1976, one can find specific reference – in the energy context – to the idea of “sustainable urban structure” in an exploration of alternative urban forms that can sustain living standards in the face of energy shortages (Seed, 1976). The Brundtland report itself recognizes the role of cities in sustainability and the United Nations Conference on Environment and Development (UNCED) (see Section II.1) produced *Agenda 21*<sup>6</sup> which included a “Local Agenda 21” component, which spawned its own movement.

The fact that metropolitan areas continue to grow the world over suggests some ongoing urbanization benefit: firms and individuals value having a relatively nearby spatial distribution of various opportunities. More formally, urbanization – and more broadly “metropolitanization” – allows for the so-called “economies of agglomeration,” with benefits accruing related to labor supply (e.g., greater possibilities for skill combinations, better learning opportunities) and firm productivity and market access (e.g., access to a wide range of possible input combinations; opportunities for firm specialization; information spillovers) (for more detail, see, e.g., Glaeser, 1998). As such, cities have played a long-standing role in economic development, at the regional, national and international level. Cities bring additional, “non-economic” benefits, such as enhanced social opportunities, and greater chances for people to find peer groups and, even, anonymity. Cities also can bring certain environmental benefits as well, offering the possibility to, for example, reduce space consumption and ecosystem impacts of human settlements (via density) and improve the efficiency of delivery and use of resource-consuming services (energy, transportation). At the same time, however, cities suffer from many well-known agglomerative “drawbacks” (and/or diseconomies); for example, congested urban networks hamper economic development, the disconnect between resource use and disposal can exacerbate environmental degradation, and crowded living conditions can increase disease transmission and, possibly, crime propensity. Local environmental problems are severe in many developing country cities, while by far the largest concentrations of the world’s wealth resides in developed cities which make them the greatest “load on the ecosphere and global commons” (Rees, 1997; p. 304). Cities, or urban areas more generally, are thus critical to sustainability in all its dimensions.

Strongly credible doubts can be raised, however, regarding the idea of the “sustainable city” (or metropolitan area). These doubts relate directly to the points in the previous paragraph – a city survives by its interactions with other regions and produces impacts well beyond its borders. What a given city’s residents might view as sustainable could

---

<sup>5</sup> In 1972, Dickey and Broderick (1972) propose a simplified urban functional system in four dimensions: *man*, the *natural environment*, the *man-made environment*, and *activities*. The last one functions as a synthesizer of the other three: since activities take affect and are affected by relations with the others. This framework shows a clear direct link to the ideas embedded in the capital or dimensional conceptualization of sustainability.

<sup>6</sup> The Conference also produced the Rio Declaration on Environment and Development and the Statement of principles for the Sustainable Management of Forests.

well be a threat to “larger” (i.e., global) sustainability. Ryan and Throgmorton (2003) make this point when observing that a community outside Chula Vista (California), has opted to “sustain certain transportation and land use qualities which may not be sustainable in a global sense” (p. 50). This reflects back to Rees (1997) point above, regarding the relative contrast of environmental problems between developed and developing world cities. It also sheds some doubt on the Kuznet’s curve, or technological optimist types (associated with the “weak” sustainability paradigm, mentioned in Section II.2). But, again, at some point it depends on what we are really concerned about in terms of sustainability and what, exactly, it is that we are trying to sustain (ourselves, our cities, our planet)?

Finally, in considering boundaries, we cannot ignore the somewhat arbitrary political units that typically define urban areas. Many cities today are multi-jurisdictional amalgams, with urbanization constantly expanding and encompassing new areas. Where does the “city” end? This is a critical issue, not only for data collection and indicator development, but – on a practical level – for many metropolitan management and coordination functions (e.g. land use, transportation, air quality, water quality, affordable housing provision; see, Wheeler 2000). For example, Portney (2003), in a recent attempt to assess the degree to which U.S. cities are “taking sustainability seriously,” considers cities to be a relevant unit of analysis both because a city has to confront, head-on, many sustainability issues (such as waste disposal) and because city governments are close to the populace. At the same time, however, he notes that the city may be too small of a unit to make much of a difference for many of the larger problems. A related point is that ecosystems and governmental units rarely match up (see e.g. Gustavson et al 1999), except in specific cases such as watershed or air quality management districts.

### **II.3.1 City Planning, City Design, and Sustainability**

The city, in some form or another, represents one of human-kind’s most enduring physical presences on the planet. Across much of the world, one can find still-functioning urban areas (or at least parts of them) dating back to at least the first Millennium. Even in the so-called “new” world (i.e., the Americas), some of the colonial cities (e.g., Cuzco, Perú) preserved the basic physical structures built by the local cultures that had been conquered and ostensibly “replaced.” In this sense, many cities manifest at least one aspect of sustainability: passing on a stock (human-made) from one generation to the next. This inherited stock embodies the cultural beliefs and functional purposes of its origins, which might be religious (e.g., Lynch’s idea of the “cosmic city”) artistic (or artistic-religious, i.e., the “Renaissance”), economic (industrialist, capitalist, socialist), and/or philosophical (the “utopian”). Not all cities were/are planned, but even the unplanned city represents some underlying belief system within the relevant culture (e.g., Houston, TX).

The birth of the 20<sup>th</sup> Century came at a time of rapid developments in the sciences (e.g., Relativity in physics and Darwinism in biology), technologies (e.g. internal combustion engines, telecommunications), management (e.g., the assembly line and “science of management”), public policy (social sciences), philosophy (e.g., logical positivism), and the arts/design (e.g., modernism). The convergence of these developments, indeed in

many cases their explicit integration, could be seen in many different fields and disciplines, including in architecture and the nascent profession of city planning. These intellectual and scientific developments coincide with important demographic dynamics – in fact some of these developments come, at least in part, as a response to these demographic dynamics: exponential population growth and urbanization. Indeed, mass industrialization and urbanization go hand-in-hand: technological advances brought increases in human longevity, urbanization intensified, creating strong pressures to settle and house ever-larger populations and economic activities and the growing rejection of the sometimes Dickensian conditions associated with early industrial urbanization.

These pressures, plus technological innovations (in energy, transport, building technologies, etc.) increased the importance of rapid, and affordable, urban development schemes and architectural-design-planning ideas of “the city as machine.” These are, of course, the ideas underlying modernism, which in architecture/planning circles finds formalization in the CIAM (Congres Internationaux d'Architecture Moderne) and its well-known “Athens Charter” of 1933, with the theme the “Functional City.” The functional city emphasized efficiency (e.g., limited access highways<sup>7</sup>), simplicity in design, and separation of uses (e.g., single use zoning, and streets exclusively for traffic) (see, e.g., Beinart, 2004). The ultimate goal derived from the fundamental belief that social order could be influenced by the built space and, thus, the pre-eminence of functionality in city planning and design. The maxim associated with this philosophy is the well-worn “form follows function” (i.e., function is what is important). In terms of urban theory, the ideas of modernism can also be found in the “Chicago School” (see, e.g., Dear and Flusty, 1998), the early urban sociologists’ attempts to apply scientific analysis to urban form and dynamics, evidenced most notably (and enduringly) by Burgess’ 1920s theory of the zonal or concentric ring, aiming to explain the social differentiation of urban areas (see, e.g., Robson, 1969).

While the multiple strands of the relevant planning theories and practices cannot strictly be defined within a single category (or philosophy), per se<sup>8</sup>, the modernists believed, ultimately, in the construction of better societies through the construction of settlements. In this sense, the modernists shared with other influential planning theories of the time (e.g., Howard’s “Garden City”) – all were counter-reactions to the widely perceived ills of the late 19<sup>th</sup> Century industrial metropolis. In practice, elements of strict modernism (Le Corbusier’s “radiant city” “city as machine”) would be combined with aspects of the “garden city”/“garden suburb” into the predominant pattern of urban and suburban development in the United States (and, later, in most other urban/suburban development projects around, at least, the Western world): characterized largely by separation of uses, urban “renewal” (demolition), wide radial avenues/highways, etc.<sup>9</sup>

---

<sup>7</sup> Le Corbusier – one of the founders of the CIAM and possibly the most well-known modernist architect and city planner – was one of the first city planners to recognize the powerful urban force that would be the automobile.

<sup>8</sup> It is well beyond my research scope (or capabilities) to delve into the multiple variations of and debates on modernism, pre-modernism, and postmodernism.

<sup>9</sup> Outside the “West,” modernism would also be adopted, and is also associated with the loaded word: *modernization*.

By at least the 1960s, however, an increasing wave of discontent grew in reaction to the perceived ills brought on by modernist “extremism,” such as massively disruptive urban revitalization projects and sprawling “cookie-cutter” suburbs. Conveniently, and not coincidentally, by this point a broader cultural counter-reaction to modernism emerged, the so-called postmodernism – epitomized by diversity in perspectives, beliefs, traditions and lifestyles and a rejection of universal truths.<sup>10</sup> Postmodern ideas gain traction in planning theory, and in some cases, planning practice as well. Some associate postmodernism in urban planning/design with relatively distinguishable characteristics in comparison to modernism (e.g., Hirt, 2003 and Table II-1). Others, however, interpret postmodernism’s relevance to planning more dubiously. Beinart (2004), for example, notes elements of postmodernism in planning theory and design beliefs (“heterotopia,” “eclecticism”), but suggests that the idea of the “postmodern” city cannot be defined. Newman (2000) recognizes the value of postmodernism in celebrating differences, in thriving on the “lack of absolutes,” but despairs at its cynical views on the future and pessimism regarding the possibilities for progress.

**Table II-1. Hirt’s Juxtaposition of Modernism and Postmodernism in Planning**

<b>Planning Area</b>	<b>Modernism</b>	<b>Postmodernism</b>
<i>Authority</i>	Secular, single, strong	Multiple, competing,
<i>Philosophy</i>	Scientific rationalism, single truths	Contextual, subjective, individual truths
<i>Goals</i>	Material growth, physical security, basic human survival	Well-being, quality of life, values, ecological protection
<i>Processes</i>	Ordered, hierarchical, comprehensive, linear, large-scale, technologically “rational” and “efficient”	Advocacy planning, collaborative planning, communicative planning, consensus-building
<i>Resulting Forms</i>	Urban renewal; urban segregation (uses); new development (greenfields)	Historic preservation; cultural diversity; mixed uses; “human-scale” and “traditional”

Source: Derived from Hirt, 2003.

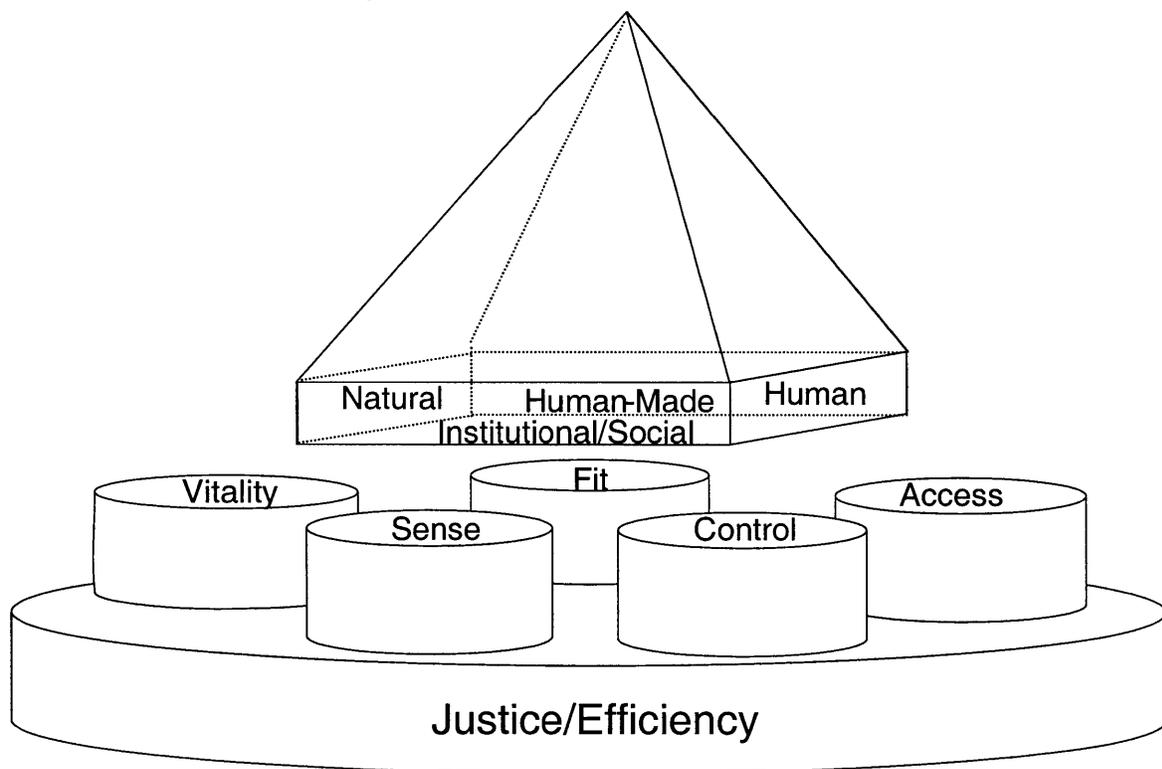
This discussion is more than simply pedantic, because city design and planning theories and their products – cities or human settlements more broadly – represent the prevailing philosophies of the time and the values of the people building and inhabiting them. Rather than attempt to propose that today we are planning cities either in a “modernist” or “postmodernist” mindset (or value system), I think today we are operating in some value space synthesized from the modern/postmodern perspectives.<sup>11</sup> And, the concept of the sustainable city fully symbolizes this synthesis. For example, many might interpret

<sup>10</sup> Just as modernism cannot really be captured singularly, postmodernism represents a broad range of artistic, philosophical, intellectual and cultural currents and activities; there is no single agreed upon definition of the term’s meaning or “membership.”

<sup>11</sup> This synthesis “space” can be thought of as arising from a modern-postmodern dialectic (in the tradition of Kant, Fichte, Hegel, and Marx), meaning a process of change in which a concept passes through the stages of thesis, antithesis and synthesis and by which the concept ultimately is “preserved and fulfilled by its opposite” (Merriam-Webster, 1996).

the typical “prescriptions” for the sustainable city to contain much of the characteristics inherent in postmodernism: diversity (of perspectives, cultures, land uses), human-scale, participatory, ecological, and focused on “quality of life” (again, see Table II-1). At the same time, the idea of the “sustainable city” as something that we can achieve (and measure) and, furthermore, the belief that we can build, configure and operate the city to a social end (sustainability) is still a thoroughly modern concept. That elements of modernism and postmodernism exist in most of the world’s cities is evidenced in ongoing megaprojects (from Boston’s Big Dig to Shanghai’s Pudong development) and multitudes of “mini-projects” (e.g., traffic calming) and in the broad range of (in some cases increasingly integrated) planning approaches (such as large-scale urban models, cost benefit analysis, participatory planning).

**Figure II-3. Mapping Lynch’s “Good City” Performance Dimensions to the Capital Construct of Sustainability**



As discussed in the introductory Section to this Chapter, sustainability and sustainable development ultimately reflect social and cultural values and value systems. Cities, as argued here, represent important physical manifestations of those same value systems. We design cities to achieve preferred outcomes (values), whatever those preferences might be. Interpreted in this context, the idea of the sustainable city does not really mean anything new; it is simply another way of defining the “good city.” This leads us directly to Lynch’s theory of *Good City Form* (Lynch, 1984), in which he proposes a theory of city form based on fundamental human values and shows how such values lead to the notion of the “good city.” Not just theorizing on urban form, Lynch generalizes performance *dimensions* (akin to areas for performance measurement; i.e., categories for

indicators), that he suggests should be important “for most, if not all, persons and cultures” (p. 112). His five performance dimensions are: (1) Vitality, the degree to which city form supports biological requirements of humans (protects species), including the “present *and future* stability of the total ecological community” (emphasis added); (2) Sense, or allowing for clear perception and differentiation of space; (3) Fit, the degree to which the form and spaces match what people do (or want to do); (4) Access, or the ability to reach other activities, resources, services, etc.; and (5) Control, or the degree to which use and access is controlled by those who live there. Over-arching these performance dimensions, he proposes, comme two “meta-criteria”: (1) Efficiency, relating to the cost of creating and maintaining the settlement; and (2) Justice, reflecting the way benefits and costs are distributed. While Lynch developed this theory before the mainstreaming of the sustainability lexicon, his *normative* theory maps, directly, to the idea of the sustainable city. In other words, the sustainable city is the “good city,” as measured by the values of its inhabitants (see Figure II-3).

## **II.4 Sustainable Transportation & Sustainable Urban Mobility**

Questions can be raised (and not necessarily easily answered) as to whether there is any real value in attempting to analyze a sector’s “sustainability.” Beyond attempting to analyze or assess “urban sustainability,” can we further attempt to look at transportation sustainability, or more narrowly urban transportation sustainability, or more narrowly still, urban passenger transportation sustainability? Despite the unclear legitimacy of such enterprises, one does not need to look far to find references to sectoral sustainability, such as to sustainable housing, sustainable consumption, sustainable forestry, sustainable agriculture. Some of these sectors lend themselves naturally to the sustainability concept and, indeed, essentially formed the basis for modern ideas about sustainable development. For example, the German Hans Carl von Carlowitz, is largely credited with formalizing the concept of sustainability in his 1713 book on forestry practice (see, e.g., Klöpffer, 2002; Häusler and Scherer-Lorenzen, 2002). From a practical implementation perspective, sectoral indicators may well be of most interest to responsible authorities (e.g., an individual ministry) in order to gauge specific contributions to sustainable development (see, e.g., Giovannini, 2004).

### **II.4.1 Sustainable Transportation: Briefly Tracing the Evolution of a Concept**

In the transportation sector, the evolution of the sustainability concept followed a pattern similar to sustainability, more generally. Many of the problems that people today associate with threats to the “sustainability” of modern transportation – such as air pollution, traffic safety, sprawling urban development patterns, automobile dependence, etc. – have been recognized, lambasted and, to some degree or another, addressed by policy-makers regulators and the general public for over 50 years. Motor vehicle pollution regulations find their origins in late 1950s legislation in California, which would lead to the state passing the nation’s first tailpipe emissions standards in 1966 (CARB, 2004). By at least the mid-1960s, some degree of US Federal Government rhetoric on the dangers of urban “sprawl” can be found (Weaver, 1965). The first global energy crisis of the 1970s implicitly introduced an important aspect of sustainability to

transportation: the potential reliability of the sector's primary energy source, petroleum.<sup>12</sup> In their seminal book on public transportation and its inter-relations with land use, Pushkarev and Zupan (1977) highlight the problems they consider increasingly evident as a result of "dependence on the automobile," including: mobility for the disadvantaged, energy use and environmental effects, space constraints (from infrastructure provision). These same problems would eventually become widely associated with the negative impacts of transportation as outlined in the broader sustainability framework.

It is not clear when, formally, the concept of sustainable transportation – as understood in the post-*Limits to Growth* context – emerges. Few explicit references can be found before 1989.<sup>13</sup> Notably, Newman and Kenworthy have a paper on urban form, transportation and fuel consumption, presented at a conference session on *sustainable* urban form in Adelaide in 1980.<sup>14</sup> In the immediate wake of the Brundtland report, Replogle (1987) presented a paper at the 1988 Annual Meeting of the Transportation Research Board on "sustainable transportation strategies" for the developing world.<sup>15</sup> In that paper, Replogle, notes how the concept of sustainability – growing in influence in the development community at the time – had not yet had much impact in the transportation sector and he explicitly makes the link between transportation, basic human needs, and environmental effects. In 1989, Hanson analyzes urban transportation and population growth and subsequent energy use and emissions in Mexico City and Jakarta, suggesting an evolution towards "non-sustainable futures" and "non-sustainable urban forms" (Hanson, 1989). In 1991, Replogle (1991), building upon his earlier work, considers the concept of sustainability vital for transportation development, calling for "a more holistic approach to policy and investment planning" and contrasting existing patterns of transportation with more "sustainable" transportation and land development patterns.

*Agenda 21* (see Section II.3) explicitly mentions the transportation sector (along with other sectors) and its "essential and positive role" "in economic and social development." Transportation, together with other sectors covered in Agenda 21's Chapter on "Protection of the Atmosphere," is recognized as key to development, but also as a major threat to development due to its contribution to atmospheric emissions as well as "other adverse environmental effects" (UN DSD, 1992). Also in 1992, the Commission of the

---

<sup>12</sup> During this era, the Transportation Research Board's (TRB, of the U.S. National Research Council) relevant committee was on "Energy Conservation and Transportation Demand" (e.g., circa, 1975).

<sup>13</sup> A database search on the terms sustainability and transportation (and sustainability and transport and sustainable and transport) (looking for the terms anywhere in a document) turns up few references before 1989. The search was done on WebSPIRS' bibliographic database of transportation research and economic information, which combines databases from three sources: TRIS (Transportation Research Board), IRRD (Organization for Economic Co-operation and Development), and TRANSDOC (European Conference of Ministers). A few references include the word sustainable as it relates to: public transport finance in the face of privatization and deregulation in the UK during the 1980s and economic development and infrastructure in developing countries in the 1960s.

<sup>14</sup> The authors could not provide a copy of the specific paper presented at that conference, but suggested to me (personal communications with both authors; May, 2005) that it was related to their early research on transportation, energy use, and urban development patterns in Australian cities (e.g., Newman and Kenworthy, 1980).

<sup>15</sup> The paper was written in 1987 and presented at the January 1988 TRB meeting; Replogle provided me with an electronic copy of the original 12/15/1987 paper.

European Communities (CEC), in a document on the development of its common transport policy, established a framework for *sustainable mobility*.<sup>16</sup> By the end of 1994, the Organization for Economic Co-operation and Development (OECD) essentially takes up the cause, when a OECD-convened Expert Group on transport and the environment called for, as the first phase of a four-part study, the development of “a definition of environmentally sustainable transport (EST)” (OECD, 1996).

In some respects, the OECD effort marks an important point in the “mainstreaming” of the idea of sustainable transport; yet the focus remains primarily on environmental effects, evidenced by the name of the OECD project launched by the mid-1990s: the *Environmentally Sustainable Transport (EST)* project. Around the same time, however, the World Bank – which as mentioned in Section II.2 was already, presumably, only funding projects that were socially, economically and environmentally sustainable (Serageldin, 1996) – published its new transportation policy, founded on the these same three principles of economic, environmental and social sustainability (World Bank, 1996). Thereafter come a steady stream of projects, definitions, and initiatives from the private sector, non-governmental organizations, and others which will, essentially, all embrace the multi-dimensional aspect of sustainable transportation (examples include, e.g. WBCSD, 2001 and CST, 2002; reviews of relevant initiatives can be found in, e.g., Lee et al., 2003 and Jeon and Amekudzi, 2005). Clearly, these efforts show recognition of the need to look at sustainability in a broad, multi-dimensional framework; at the same time, however, they suggest a degree of opportunism, an attempt to make sustainable transportation all things to all people and, thus, lose any real meaning. Who could argue with the idea of a sustainable transport system, when ultimately the phrase has become synonymous with “good transport” (akin to the “good city”)? But, what, actually do we mean by the term sustainable transport? In some ways, sustainable transportation, like its relative, the sustainable city, has become a postmodern term applied to a thoroughly modern concept.

#### **II.4.2 Sustainable Transport: Examples of Definitions and Principles**

The now-ample literature on sustainable transportation contains no dearth of explorations into the meaning of, purposes to, and means for achieving “sustainable transport.” And, while some degree of complementarity exists among the wide-ranging explorations, any attempt to concisely review the many viewpoints faces the challenge that, quite often, even a single document will confuse, or at least not clearly differentiate, goals (i.e., an articulation of values), objectives (i.e., a measurable end), and indicators. In some cases, this is because some work jumps immediately to what sustainable transport should be (e.g., “based on a diversity of modes”), while others focus more on objectives and principles (e.g., “sustainable transportation meets the mobility needs of all”). One finds that, for the most part, the basic principles are the same, but that actual definitions tend to vary, sometimes significantly, and that few if any, *operational* definitions (see Section II.2) are proposed.

---

<sup>16</sup> The document, as cited in Rienstra and Piers, (2000), was titled *The Future Development of the Common Transport Policy: A Global Approach to the Construction of a Community Framework for Sustainable Mobility*.

In his seminal paper on sustainable transportation, Replogle (1987) embraces the concept in its multiple dimensions, suggesting that a “sustainable transport strategy” would be guided by economic and financial *principles* (“economic viability, financial viability, and efficiency”) together with environmental viability and “equitability, distributional viability, or effectiveness” or the “the degree to which the transport system meets the basic mobility needs of everyone.” These multiple dimensions can be found in many subsequent definitional *attempts*, with emphases varying depending on the perspective.

From the international organization perspective, for example, the World Bank’s 1996 policy document takes – predictably – an economic-oriented focus, emphasizing the efficient use of resources and proper maintenance of assets (economic and financial sustainability); full consideration of “external effects” (environmental and ecological sustainability) and broad distribution of transport benefits (social sustainability) (World Bank, 1996). In contrast, the OECD’s Environmentally Sustainable Transport (EST) project originally had – as the name would suggest – a decidedly environmental tilt, *defining* a sustainable transport system as one that meets *access* needs without endangering “public health or ecosystems” in a way consistent with no net decline in the stock of renewable and non-renewable resources (OECD, 2002). The OECD goes on to more specifically define a sustainable transport system based on fulfillment of WHO guidelines for air pollution, noise levels, acidification, and eutrophication, as well as general international goals related to climate change and stratospheric ozone depletion.

An oft-cited non-governmental organization perspective comes from the Canadian-based Center for Sustainable Transportation (CST), which – similar to the OECD EST definition – builds on the concept of *access*, identifying the need to fulfill “basic access needs” within human, ecosystem, and economic/financial limits and in consideration of equity within and between generations (CST, 2002). The CST goes on to offer general guidelines for how to make the transportation system more sustainable in social, economic and environmental dimensions. In basic principles, the CSTs definition matches that offered by a prominent industry group, the World Business Council for Sustainable Development (WBCSD), who put forth its definition of sustainable *mobility* in 2001 as “the ability to meet the needs of society to move freely, gain access, communicate, trade, and establish relationships without sacrificing other essential human or ecological values, today or in the future” (WBCSD, 2001). Arriving at the level of the *urban* transportation and *land use* system, Minken et al (2003), again define a sustainable transport in terms of providing access (to goods and services) in an efficient way, that protects natural and cultural heritages for today’s and future generations. Finally, Schipper (1996) proposes that transportation is “sustainable” when the beneficiaries pay their full social costs, including those paid by future generations.

None of the above-cited efforts, with the possible exception of Schipper (1996) offers an *operational* definition of sustainable transport, per se. Nonetheless, most involve three basic concepts: access (or accessibility), recognition of resource constraints (financial, economic, natural, cultural), and equity. The latter concept, equity, actually reflects the interaction between the other two concepts, particularly in terms of inter-generational equity – the idea that sustainability implies allowing future generations to enjoy the same

access levels as today (which, in turn, implies consideration of potential exhaustion of resources). Equity, of course, also refers to distribution within the current generation, implying some balanced distribution of transport benefits (access) and costs (reflected, in various ways, by resource constraints).

### II.4.3 System Complexity and Boundaries

We can see, then, how sustainable transportation, like sustainable development more broadly, can quickly become not just complicated, but confused. We are dealing with resource constraints over multiple time horizons with uncertain impacts (in part due to uncertainties regarding technological innovations); furthermore, we want to ensure that future generations have the same benefits from transportation as we do, while also ensuring some fair distribution of benefits today. Asking for some trade-off in inter-generational equity becomes particularly challenging in the developing countries, where, for many, sustainability literally is a day-by-day reality – living on less than one dollar a day makes it difficult to concern oneself with possible effects on tomorrow.

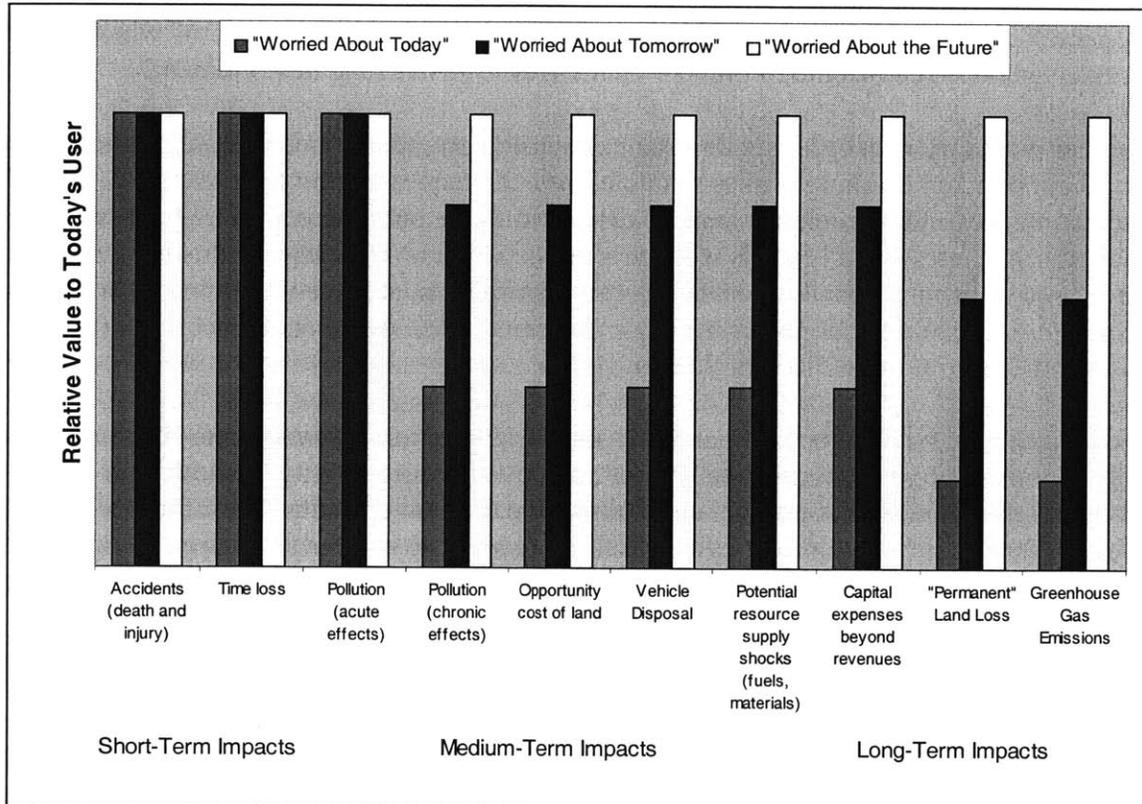
Figure II-4 provides a stylized representation of the concerns that a hypothetical person today faces, and how much she “values” those concerns based on her own sense of time importance (i.e., discount rate) *and* the approximate time-frame of potential impacts. Note that the time-frame of impacts generally correlate with uncertainties – for example, we are much more certain about the acute effects of local air pollution (short term) than we are about the possible effects of climate change (long term). But, this is not necessarily always the case.<sup>17</sup> Furthermore, we might expect (as from basic economic theory) a relation between discount rate (i.e., how much we value the future) and wealth; again, however, this may not always be the case.<sup>18</sup> For the transportation system, to current users (or contemporaries affected by current system use) the threats to immediate sustainability are short term effects (in terms of the period over which it takes the threats to materialize). In other words, the main threats to sustainability are those that impact our immediate existence, such as accidents that kill or maim us, pollution that can make us acutely ill (or make it acutely difficult to sleep or rest), or loss of time that might make us late for work (or lose our job). Of course, there are trade-offs among these threats, and we do not necessarily make rational trade-offs among them – do we put ourselves and/or others at risk of death or injury (or illness) so we are not late for work? The trade-offs often regard “our own” sustainability (relative importance of different aspects within our own lives); there are also trade-offs relative to other’s sustainability. Some of this is governed by laws and regulations (e.g., seatbelt laws, speeding laws), but all is a reflection of the belief system/values. Once again, we see the fundamental role of values in the sustainability concept.

---

<sup>17</sup> The case of accident risk being a good example.

<sup>18</sup> We could imagine, using simple economic concepts, that a wealthy person might not concern himself with climate change, under the belief that he will be able to bequeath to his future generations the wealth needed to protect himself from the negative effects.

**Figure II-4. Stylized Representation of a Hypothetical Person’s Values Today as they Relate to Transportation and Sustainability and the Role of A Theoretical “Discount Rate”**



#### II.4.3.1 System Boundaries

In attempting to look at sustainable mobility, and, more specifically, sustainable *urban* mobility, we are looking at a sub-sector of a sub-sector of the world system: not just the city, but the mobility system within the city and, further (in the empirical case in this research), the passenger mobility system within the city.

The implications of trying to look at such an artificially bounded system need to, at minimum, be explicitly recognized. As one example, consider “system”-type boundaries. In isolating the transportation system, we might ignore the fact that transportation (similar to the suggestion above regarding cities), itself, is an “enabler.” In other words, transportation allows for other activities to occur, such as consumption patterns (e.g., shopping at malls, eating strawberries in wintertime) which might be, on a larger scale, “unsustainable.” This relates to fundamental debates about the sustainability of our global economy and the need to grow the economy in a “sustainable way.” Hall (2002) also recognizes transportation as “an enabling mechanism that facilitates consumption at ever increasing rates” and recommends that definitions of transportation sustainability include the issue of “throughput of natural and man-made resources,” since, according to his perspective, the use of the transportation system “can have a dramatic affect on whether the final goal of global sustainability is achieved.” According to this perspective, bounding relevant analyses of transportation systems creates a problem by

isolating them from the larger problem (global sustainable development) that we are trying to contribute to (Hall and Sussman, 2003). At the metropolitan level, we see analogous effects, as transportation investments and services can induce changes in land use patterns, such as accelerating development on the urban fringe – patterns which themselves might contribute to broader challenges to sustainable development.

Another boundary is geographical in scale. Focusing on urban transportation requires an artificial boundary that might miss sustainability challenges arising from a city's interactions beyond its region (again, as discussed in the previous section) – e.g., via trade, tourism, etc. – and impacts well-beyond its borders. To a degree, this is related to the idea of transportation as an enabler – can metropolitan areas (and their own, bounded, sustainability) enable a larger, unsustainable system? See, the related discussion (e.g., Ryan and Throgmorton, 2003) in Section II.3.

The idea of geographical scale-boundaries manifests itself in an *intra*-sectoral way as well. For example, the roughly stable *average* travel budgets (i.e., percentage, on average, of income spent on travel and hours per day spent on travel) that, for example, Schafer (2000) shows empirical evidence for could lead to shorter urban trips being replaced by longer inter-urban travel, as travelers use the time and money saved via ostensibly more sustainable urban travel behavior and invest it in longer distance, high speed travel (including by air). Again, such behavior may produce locally more sustainable outcomes, but with adverse global sustainability effects. Other boundary-related concerns at the intra-sectoral level arise from the isolation of passenger travel from freight; again, an artificial and awkward separation because passenger travel behavior affects freight travel, and vice versa, and because the lines between freight and passenger travel become blurred with, for example, home delivery of goods.

#### **II.4.4 Transportation and Indicators**

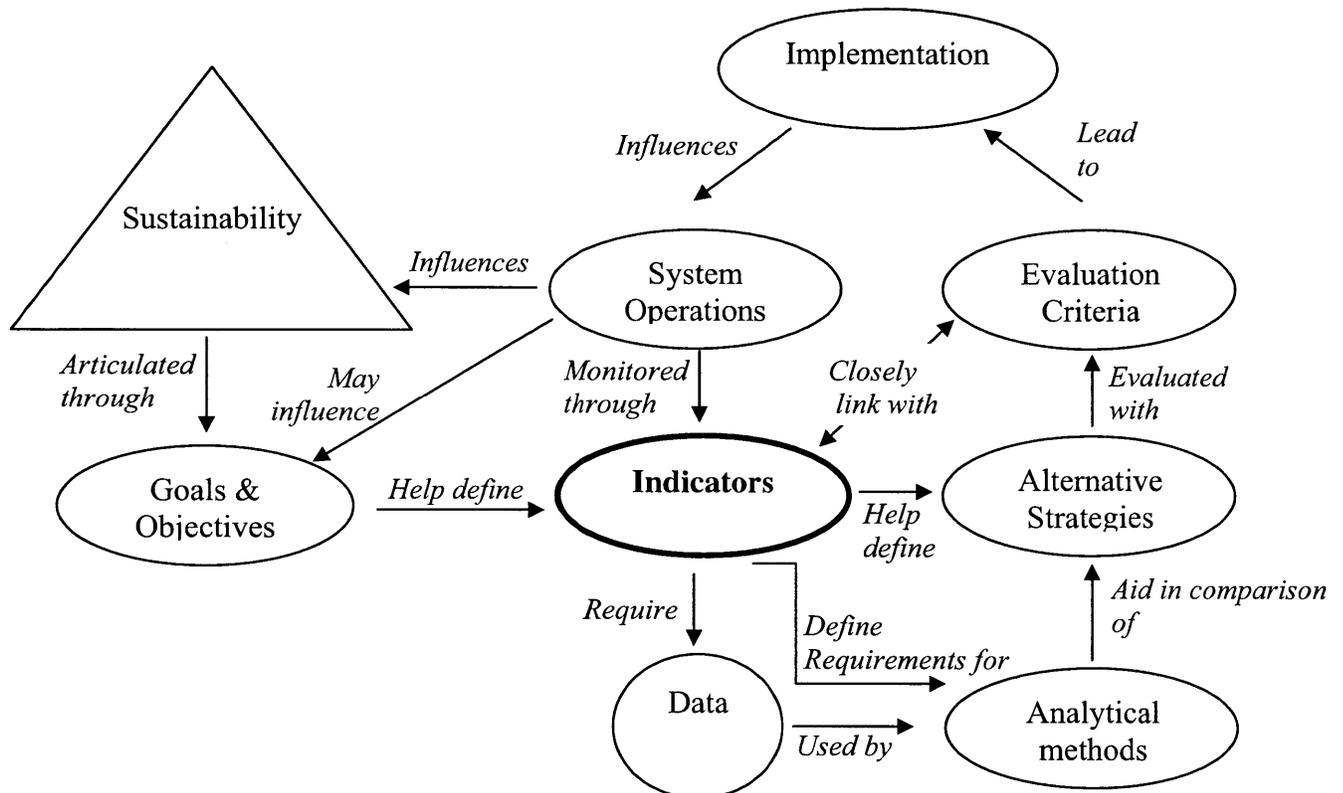
The use of indicators in transportation is not, of course, new. For example, a long-used indicator for assessing system performance – particularly roadway system performance – is level of service (LOS), basically derived from vehicle volumes and roadway capacities. Working based on rankings – A through F – measures of LOS are used to help identify current and future system congestion. LOS offers a relatively straightforward measure, while the sustainability perspective clearly requires a more comprehensive set of indicators to reflect transportation system performance. As depicted in Figure II-5, in transportation planning (although the Figure generically could represent any planning activity), indicators, which require data, reflect the overall goals and objectives, help define alternative strategies and the analytical methods used to evaluate those strategies, and ultimately aid in monitoring system performance.

##### *II.4.4.1 The Role of Indicators in Transportation*

Indicators in transportation are related to what Meyer and Miller (2001) call “performance-based transportation planning;” indeed, they form a critical component of such planning. In such a planning approach indicators are closely tied to project evaluation criteria (see Figure II-5), since, as indicators aim to reflect what is considered important these same important aspects should be reflected in evaluations. Appropriate

indicators for transportation will vary depending on the scale of the analysis (e.g., an individual facility, a corridor, a regional network [Ewing, 1995]) and on the ultimate goals, although common indicators can often apply to several different goals and/or scales of analysis.

**Figure II-5. The Role of Indicators in the Transportation Planning Process**



Source: Adapted from Meyer and Miller, 2001.

As mentioned above, in performance-based transportation planning, indicators are closely linked to evaluation criteria. For an evaluation criterion, transportation has a long history of using money, specifically, by quantifying monetarily benefits and costs. In the early years of modern transportation planning, just as facility location was the primary objective of planning activities, the primary evaluation concern was net economic benefit, as measured by benefit-cost ratios, internal rates of return, or more reliably, net present value. According to Meyer and Miller (2001), by the 1960s transportation planning – in part due to legal requirements – began incorporating a broader range of issues into the planning process, such as air quality, energy consumption, community cohesion. As this new range of evaluation criteria entered into the planning and evaluation process, some efforts have been made at quantifying these criteria, using so-called full cost accounting techniques. Although quantifying these costs can be done with the aim of incorporating the results into evaluations, more generally full cost studies aim to give a picture of system performance – i.e., to serve as indicators. The idea is that through quantification and use of a common “metric” (currency) the results can be more easily understood and evaluated on the same footing. In practice, full cost studies are wrought with difficulties. In a review of five “full cost” studies (four for the United

States and one for Europe)<sup>19</sup> carried out in the early 1990s, Gómez-Ibáñez (1997) identifies five “pitfalls”: failures to clearly identify the market and policy context; insufficient care in measuring relationships between use and cost; reliance on average cost to proxy marginal costs; inconsistency in definitions; and the use of control instead of damage costs (when the latter are available).

Performance-based transportation planning and the role of indicators can be thought of within the hierarchy of the Sustainable Indicator Prism (Figure II-1). The top of the pyramid represents the goals (i.e., articulation of values, what we mean by sustainable transport) and objectives (the measurable end, or indicator), with the performance measures (indicators of varying degrees of specificity), building from raw data at the pyramid’s base towards composite indices which converge towards the goals at the top. Those, such as Ewing (1995), who call for a “paradigm shift” in transportation performance measurement, seem to be making an explicit push towards shifting goals and objectives, with subsequent changes in measurement approaches required. Ewing says, for example, that we need to move away from speed-focused measures, towards a uniform approach based on the *accessibility* and *sustainability* paradigms. Litman (2003) suggests indicators can be categorized according to whether they are traffic-based (such as vehicle trips and roadway level of service), mobility-based (such as person-miles), or (3) accessibility-based (such as generalized travel costs). Again, Litman’s call might be considered as a push for a paradigm shift, or changing the goals and objectives of transportation performance.

#### **II.4.5 Sustainable Transportation Indicators**

A direct bridge between most traditional transportation evaluation criteria and sustainable transportation concepts can be found in the World Bank’s 1996 Transport Policy (World Bank, 1996), in which they orient the discussion around “rigorous economic appraisal” and the need for “appropriate price incentives” (World Bank, 1996). Again, this points towards the concept of “full-cost” accounting, and can be tied to Schipper’s (1996) sustainable transport definition, mentioned above. Taking such a tack to measuring transportation sustainability reflects the “weak sustainability” perspective (see Section II.2).

As regards specific sustainable transportation indicators and indices, various relevant efforts exist. In 2001 the WBCSD proposed 12 indicators, grouped into categories of measures to be increased (access to means of mobility, equity in access, appropriate mobility infrastructure, inexpensive freight transportation) and measures to be reduced (congestion, “conventional” emissions, greenhouse gas emissions, other environmental impacts, community disruption, accidents, nonrenewable energy demand). In their follow-up study, the WBCSD (2004) chooses a different set of indicators: accessibility, financial costs, travel time, reliability, safety, security, greenhouse gas emissions, environment and well-being impacts, resource use, equity, public revenues, and business rate of return. To some degree, these measures reflect a focus on tangibles, particularly those items that might be of interest to a business manager. At the same time, the WBCSD 2004 indicators seem somewhat redundant, particularly when one considers

---

<sup>19</sup> The World Bank (2002) includes reference to 13 such studies from developed and developing countries.

theoretically rigorous definitions of, for example, accessibility (discussed further in the next Chapter). Other efforts include, e.g., Litman (2001), who proposes a number of indicators, primarily oriented around personal and household mobility and including indicators such as: average portion of household expenditures devoted to transport; average amount of residents time devoted to non-recreational travel; medical costs attributed to transportation. Black (2000) notes that Litman's indicators have a strong equity focus and are not clearly linked to system sustainability, per se.

Recently, Lee et al (2003) find 31 “promising” transport indicators derived from the literature. Jeon and Amekudzi (2005) also offer a review of multiple recent studies which, ultimately, leads me to two conclusions: (1) the overwhelming number of indicators derived and (2) the failure to make clear the links between the proposed metrics and the goals/objectives. The multiple indicator initiatives – and numerous indicators thereby derived – represent ambitious efforts to provide a comprehensive picture of sustainable transportation. Coming from different perspectives, such as the business sector (e.g. WBCSD, 2004), the social advocate (e.g., Litman, 2001), or the academic (e.g. Lee et al, 2003), these initiatives will naturally differ in outcomes. They reflect different *purposes*, different *scales*, and, to some extent, different *value* systems. They do, however, share at least two basic characteristics. First, they reflect a “bottom-up” approach to indicator development and use, meaning they outline numerous important indicators building, metaphorically, from the base of the Sustainable Indicator Prism (Figure II-1). Second, they lack a common communicative framework towards the top of the prism – basic language that explicitly reflects a common understanding of goals and objectives. The bottom-up approach to indicator development, while critical to ultimately providing the necessary information for understanding how and whether we are moving towards the goal of sustainable transport, can become difficult to sort through without a clear articulation of goals and objectives. Developing sustainable transportation indicators becomes something of a measurement game.

#### *II.4.5.1 Sustainable Transport Indices?*

As mentioned, indices converge towards the top of the Sustainable Indicator Prism (Figure II-1). Not as many efforts on sustainable transport index development can be found in the literature. Litman (2001) lists his indicators in a call for the development of a “sustainable transportation index.” Black (2000) moves in this direction, using principal components analysis to derive an index from indicators of: fossil fuel dependence, air emissions impacts, traffic accidents, and congestion effects. Importantly, he recognizes the “one-sidedness” of the resulting index, which he says raises “some questions regarding what we are really trying to measure,” pointing out – essentially – that an index must be capable of reflecting environmental sustainability *and* mobility. Ultimately, he envisions an overall sustainable transport index that points to the underlying trade-off between mobility and sustainability (viewed from an environmental perspective). Along these lines he proposes a research direction that seems to follow the approach of Neumayer's (2003b) combination of the HDI and genuine savings rates, discussed in Section II.2.1. Zietsman and Rilett (2002), looking at specific travel corridors, take a bottom-up index creation, using multi-attribute utility theory (MAUT) to derive an index as the weighted sum of several normalized mobility indicators (e.g. standard deviation of

travel time, travel rate, LOS) plus local pollutant emissions, noise levels, and fuel consumption. More recently, Yevdokimov (2004) proposes to measure transportation sustainability through the Genuine Progress Indicator (GPI) (akin to the ISEW, see Section II.2.1), aiming to capture changes in social welfare due to transportation.<sup>20</sup> Finally, at least two examples exist (both from the UK), of applying the ecological footprint approach (Barrett and Scott, 2003; Wood, 2003), which, as mentioned in Section II.2.1, provides an example of a “strong sustainability” index.

#### *II.4.5.2 Direct Precedents*

Since the research undertaken in this dissertation ultimately concerns sustainable *urban* mobility, several relevant projects merit mention. The SPARTACUS project, looked at sustainable transportation in 3 cities in Europe (Helsinki, Naples, Bilbao). The analysis was forward-looking, aiming to assess the effect of policies on urban transportation sustainability, using an integrated land use transport model (MEPLAN) with tools to calculate spatially disaggregate indicators (see Table II-2) and indices (Lautso and Toivanen, 2000). The approach can be categorized as bottom-up in its construction.

Kennedy (2002) takes a comparative modal approach, aiming to assess the relative sustainability of auto travel versus public transport travel in the Greater Toronto Area (GTA), Canada. He adopts a macroeconomic perspective, looking at transportation costs from the perspective of the region (quantifying the value of the GTA’s trade relating to transportation) and also estimates accessibility benefits based on relative speeds and a time-constrained cumulative accessibility-to-work measure. Black et al (2002), looking at the Sydney, Australia case, simply bypass indicator development by accepting the New South Wales Government’s defined vehicle kilometers of travel (VKT) targets for 2010 as the primary sustainability indicator. They go on to look at variation in automobile VKT based on differences in urban form across Sydney’s 40 government areas (LGAs).

As part of another multi-city European initiative, the PROSPECTS project starts with an explicit definition (mentioned in II.4.2), maps objectives to that definition, and develops indicators relevant to each objective (Minken et al, 2003). Geared towards policy development for specific cities, the effort builds heavily on travel forecasting and land use planning tools. Finally, Kwok and Yeh (2004), looking at the case of Hong Kong, consider “sustainable development in transport” to correspond to a process that maintains “mobility while minimizing the harm it brings to society.” They then assume that public transport better achieves that goal and proceed to measure sustainable transport by relative levels of service between the two modes. Since both the PROSPECTS project and the Kwok and Yeh initiative explicitly attempt to operationalize accessibility in the sustainable transport framework, they are discussed further in the following Chapter.

---

<sup>20</sup> The GPI includes value of services provided by transportation infrastructure, cost of commuting, cost of automobile accidents, cost of air and noise pollution by transportation, loss of farmlands and wetlands and some others. Yevdokimov’s approach is not entirely clear in the paper, but he uses this formulation to measure changes in transportation’s contribution to GPI in Canada over the period 1990-2002.

**Table II-2. Indicators Used in the SPARTACUS project.**

<b>Sustainability Dimension</b>	<b>Area</b>	<b>Indicators</b>
<b>Environmental Indicators</b>	<i>Air Pollution</i>	Transport emissions of greenhouse gases, acidifying gases, organic compounds; Consumption of mineral oil products
	<i>Consumption of Natural Resources</i>	Land coverage, Consumption of construction materials
<b>Social Indicators</b>	<i>Health</i>	Exposure to particulate matter (PM), nitrogen dioxide (NO <sub>2</sub> ), carbon monoxide (CO); Exposure to noise; Traffic deaths; Traffic injuries
	<i>Equity</i>	Justice of exposure to PM, NO <sub>2</sub> , CO; Justice of exposure to noise, Segregation
	<i>Opportunities</i>	Total time spent in traffic; Level of service of public transport and slow modes; Vitality of city center; Accessibility to the center; Accessibility to services
<b>Economic Indicators</b>	<i>Costs/Benefits By Type</i>	Transport user benefits; Transport resource cost savings; Transport operator revenues; Investment financing cost; External cost savings
	<i>Overall Indicators</i>	Total net benefits (sum of costs/benefits by type); Economic Indicator (total net benefits per capita)

Source: Lautso and Toivanen, 2000

## II.5 Conclusions

The evolution of the sustainable transportation concept has followed, in most ways, the path of modern concepts of sustainable development more broadly. The idea of sustainable development can be traced far back in economic and natural resource theory and practice, raising some doubts as to whether it truly means something new – representing a paradigm shift – or simply a re-articulation of ideas that have been with us for generations. At the least, the modern sustainable development dialogue attempts to more firmly situate the multiple sustainable development dimensions on equal footing; furthermore it signifies a more explicit recognition of potentially exhaustible resource stocks. This latter point leads to identification of two basic schools of thought, weak sustainability and strong sustainability, which refer to beliefs regarding the substitutability of human-made for natural capital. Neither school of thought is currently falsifiable (e.g., Neumayer, 2003b), which means that sustainable development ultimately becomes a value-laden concept. Multiple efforts have attempted to measure sustainable development, including multi-indicator initiatives in the various sustainability “dimensions” and composite indices, using, for example, GDP-type approaches.

Indicators and indices can reflect both the weak and strong sustainability paradigms. The Sustainable Indicator Prism (Zegras et al, 2004) offers one conceptual way to understand the sustainability dimensions, their contribution to achieving the overall goal (sustainable development), and relevant links to/relationships among raw data, indicators, and indices.

In the urban setting, sustainability concepts again have been around for far longer than the actual modern definition of the term. More recently, formalization of urban sustainability or sustainable urban development has been an area of active research, including through numerous indicator initiatives. But, just as sustainable development is, ultimately, a value-laden term, in the urban setting the concept inevitably comes loaded with our values. In fact, I show that sustainability in the urban setting is clearly consistent with, arguably, the two most prominent human value systems influencing urban theories in the past Century – modernism and post-modernism. The idea of sustainable urban development actually reflects a synthesis of the modernist/post-modernist perspectives. Finally, after recognizing the consistency of sustainable urban development ideas with prevailing value systems, I show how these ideas map directly to a prominent – and explicitly normative – urban design theory, Lynch’s theory of *good city* form. This again leads us to some doubts as to whether sustainable urban development means anything new, or simply a new articulation of existing paradigms.

Finally, in transportation, the sustainability idea is ubiquitous today, with relevant initiatives originating from the public sector, the private sector, non-governmental organizations, academia, etc. The efforts, often highly ambitious, have not been matched by common language and sometimes confuse definitions, principles, and prescriptions. This may partly result from the complexity of the concept, which typically requires the imposition of some sort of boundaries (in space, scale and within the sector itself). Such boundaries may, in fact, mask the broader sustainability challenges (e.g., Hall and Sussman, 2003). Further complications arise from the fact that sustainability is inherently value-laden, arising again from different schools of thought (i.e., weak versus strong sustainability) and variations in, for example, discount rates (concern for, and uncertainties about, the future).

The move towards sustainable transportation indicators matches a broader shift towards performance-based transportation planning, which itself reflects a move towards more comprehensive multi-dimensional transportation planning, underway since at least the 1960s (e.g., Meyer and Miller, 2001). Performance-based planning requires clear goals and objectives and, then, the development of relevant metrics, an approach clearly compatible with the hierarchical information and management structure implied in the Sustainable Indicator Prism. Many sustainable transportation indicator initiatives have, however, failed to explicitly situate themselves within such a structure, lacking clear objectives (i.e., an operational definition). Hall (2002) argues that indicator initiatives will play a key role in pushing forward the sustainable transport agenda, while Ryan and Throgmorton (2003) suggest such initiatives will be crucial to comparative analyses. Getting there, however, requires common concepts and definitions. Most of the efforts help us move in the right direction and some contain many, if not all, the critical elements. Building on these, the next Chapter derives an operational definition of sustainable mobility and proposes a relevant metric.

### III

## ACCESSIBILITY & MOBILITY: TOWARDS AN OPERATIONAL DEFINITION AND METRIC FOR SUSTAINABLE MOBILITY

### III.1 Sustainable Mobility: Defining and Measuring

In considering the prospects for sustainable mobility, we first need to recognize what, exactly, we are attempting to sustain. In the case of passenger transportation, the system and the mobility services it provides serve a primary purpose: allowing access to daily wants and needs (e.g., to stores, schools, friends, work, recreational opportunities). In other words, transportation provides *accessibility*. We cannot, however, ignore the idea of transportation and mobility as end itself – in the form of, for example, “joy riding” or the “thrill of travel.”

Accessibility can be defined as the “extent to which the land-use and transportation systems enable (groups of) individuals to reach activities or destinations” (Geurs and van Wee, 2004; p. 128). As such, accessibility depends on the performance of the transportation system, on the patterns of land use, the individual characteristics of firms and people, the overall quality of “opportunities” available and, increasingly, on the communications system (see, e.g., BTS, 1997; Shen, 1998) (Table III-1). Accessibility measures have a long history in geography, transportation and urban planning studies, and have been proposed as economic and social indicators since at least the 1960s (see, e.g., Wachs and Kumagai, 1973).

**Table III-1. Accessibility: Influencing Factors**

<b>Factors</b>	<b>Effect on Accessibility (all else equal)</b>
Transportation	Improved with more links, faster or cheaper service
Spatial distribution of “opportunities”	Improved if proximity of opportunities is increased
Individual (personal/firm) characteristics	Improved with physical, mental, economic ability to take advantage of opportunities
Quality of opportunities	Improved with more, or better, opportunities within same distance/time

Source: derived from BTS, 1997.

As discussed in the previous chapter, the specific concept of accessibility (or access) as the transportation benefit that, at a minimum, needs to be sustained appears in several definitions of sustainable transportation, including that of the OECD’s EST (OECD, 2002), the Canadian Center for Sustainable Transportation (CST, 2002), a study for the Netherlands Agency for Energy and the Environment (see le Clercq and Bertolini, 2003), and – specifically for urban transportation – the European Union’s “PROSPECTS” project (e.g., Minken et al, 2003). The adoption of an accessibility-oriented definition of sustainable mobility offers the advantage of explicitly allowing consideration of the transportation-land use interaction (e.g., Martínez, 1995). Furthermore, the accessibility-as-benefit orientation is conducive to a concise, but potentially comprehensive definition

of sustainable mobility, derived directly from the “economist’s-oriented” version of sustainability as the capability to “maintain the capacity to provide non-declining well-being over time” (Neumayer 2003). If we consider accessibility as the current well-being that users derive from the transportation system, then we can, in theory at least, compare current levels of well-being with the implications (today and in the future) for achieving those levels.

The accessibility concept can also be directly linked to Sen’s (2002) proposed definition (or re-orientation) of sustainable development to mean “enhancing human freedoms on a sustainable basis.” Such an orientation seems particularly relevant in the developing country context, where expansion of opportunities (educational, social, employment, health care, etc.) is critical to human development. Referring to Sen’s (see, e.g., Sen, 1998) concepts of “functionings” (everything that an individual may wish to be or do) and “capabilities” (to achieve the functionings they have reason to choose), we can see a logical link to mobility and accessibility by considering: “functionings” as potential trip purposes and the land use-mobility system as contributing to the “capabilities” to combine, freely, “functionings” (see Table III-2). Viewed in this way, the role of transportation as an “enabler” of potentially unsustainable development patterns (see previous Chapter, Section II.4.3.1) must be counterposed with transportation’s fundamental role as an “enabler” of human development.

**Table III-2. “Functionings” & “Capabilities”: Mapping Sen’s Human Development Concepts to Accessibility and Mobility**

Sen’s Concept	Meaning	Link to Accessibility/Mobility
<i>Functionings</i>	Everything that an individual may wish to be or do (to “flourish” as human beings)	Potential trip purposes (work, school, shopping, etc.)
<i>Capabilities</i>	Freedom to achieve the “functionings” (or combinations of functionings) that individuals have reason to choose	The land use-transportation system directly influences individual’s ability to realize trip purposes and combinations of trip purposes

### III.1.1 Sustainable Mobility: An Operational Definition

I propose, then, an operational definition of sustainable mobility as:

*maintaining the capability to provide non-declining accessibility in time.*

Relative to the various approaches to conceptualizing sustainability (e.g., the three “dimensions”), this definition may be most consistent with the capital approach (e.g., Neumayer, 2003). In the context of the Sustainable Indicator Prism (Chapter II, Figure II-1), this definition aims towards the top of the pyramid. Increasing accessibility (in passenger transportation) increases human capital and, thus, we need to view this as positively contributing to sustainable development. At the same time, however, increasing accessibility requires depletion of other sources of capital: natural (in the form of fuels, lands, air, etc.), social (in the form of, e.g., the institutional and bureaucratic resources dedicated to the mobility/accessibility system), and man-made (such as infrastructures and vehicles) (see Figure III-1). Analogous to Korten’s (1995) challenge

to corporations, we want the mobility system to allocate available capital in ways that ensure that all people have the opportunity to fulfill their accessibility needs and wants (and thereby develop human capital). Accessibility provides well being (utility) to current generations, but sustainability requires that it do so without damaging the possibilities for future generations to derive, at least, the same well-being. In other words, sustainable mobility requires that the mobility benefit (accessibility) does not come at the cost of reducing capacities of essential systems to also provide welfare-increasing opportunities<sup>21</sup>. In this way, sustainable mobility can be manageably conceptualized as a balancing act between the expansion of accessibility (to health care, education, etc.) and the scarcity of resources (natural, social, and man-made capital).

**Figure III-1. “Building” on Capital: Accessibility and Sustainability**

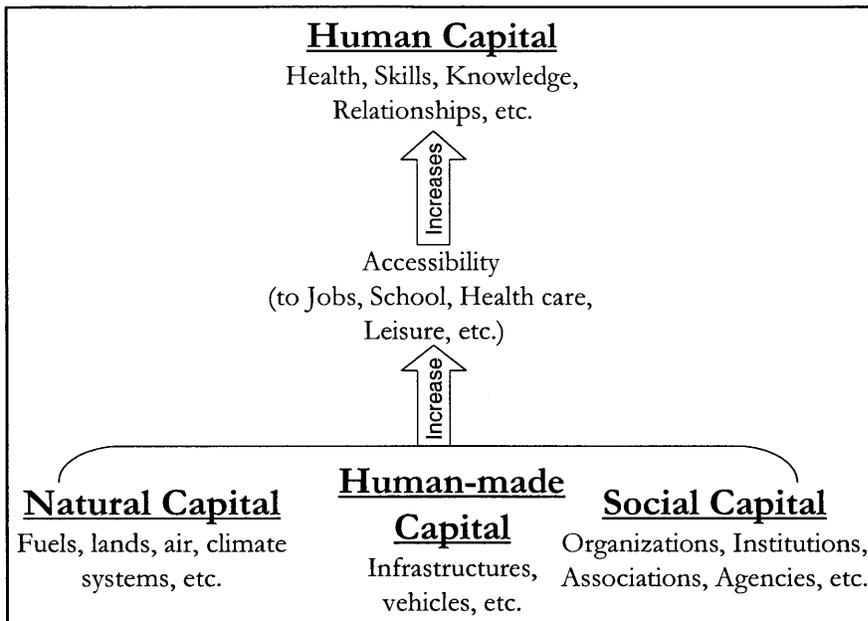


Figure III-1 obviously offers an imperfect representation. For one, it implies sequential interactions, ignoring, for example, the potential positive feedback loops such as increased levels of human capital then leading to increased possibilities to generate human-made or social (or even *re-generate* natural) capital (the “weak sustainability” perspective, see Chapter II). In addition, by its very structure – that is, with human capital “on top” – the figure might be interpreted as connoting some hierarchy of importance. That is not necessarily the intention, although sustainability is a human-oriented enterprise: we want to sustain our existence and the possibility for future generations’ existences.

This proposed operational definition of SUM leaves some issues somewhat unresolved, including:

- Inter-generational well-being. This SUM definition steers clear of the question regarding how to value current versus future generations’ benefit (utility). In other words, we do not attempt to grapple with the question of whether future generations

<sup>21</sup> Derived from Smith (2004) who does not apply it to mobility, per se.

will derive the same utility from accessibility that we do today. Nonetheless, while the definition does not give a clear answer as to how future generations' welfare should be formally treated, it does represent a first step towards an analysis that can help provide such an answer.

- Intra-generational well-being. This definition does not attempt to judge whether SUM requires a particular distribution of benefits (accessibility) or costs among today's system users. We can, however, measure the relative sharing of benefits by, for example, the construction of a Gini-type coefficient of accessibility which would allow observers to assess for themselves whether a redistribution would be desirable (more sustainable).
- Intra-sectoral value of resource use. The definition does not, necessarily, allow a direct comparison regarding whether the scarce resources dedicated to accessibility-related well-being could not be more productive somewhere else in the economy (either in another component of well-being, or in another part, e.g., of the country). Deriving an monetary value of accessibility (discussed in more detail below) could, however, enable such a comparison.

In short, my proposed definition of SUM still suffers from many of the problems that other sustainable transport definitions confront. Instead of offering a purely operational definition, the SUM definition ultimately remains as a more general form of guidance in understanding relative SUM. That is, the definition allows us to potentially recognize a *more* sustainable mobility (higher accessibility at lower total transport throughput, *ceteris paribus*); it does not tell us, however, whether this mobility will actually *be* sustainable.

### III.1.2 Sustainable Mobility: An Indicator

Despite its shortcomings, the definition proposed above and the framework represented in Figure III-1 allow us to hone in on an approximate means of measuring sustainable mobility. As an analogy, let us return to the basic idea underlying the Index of Sustainable Economic Welfare (ISEW) (as introduced in Chapter II). The ISEW, building from gross domestic product (GDP), recognizes the value of wealth (or welfare), and the fact that more wealth (welfare) is better than less. But, the ISEW – by measuring those expenses, damages, and depletions that actually reduce wealth – also attempts to gauge whether growth, at the margin, makes us poorer, not richer. Daly (2002), one of the intellectual fathers of the ISEW, calls this possibility “uneconomic growth” – growth (in throughput<sup>22</sup>) that “increases costs by more than it increases benefits” (p. 48). Many calculations of the ISEW (such as for Western European countries, the U.S. and Chile; e.g., Castañeda, 1999) suggest that a point of “uneconomic growth” – when GDP continues rising but ISEW stagnates or even falls – can be reached (and measured). Manfred Max-Neef<sup>23</sup> calls this the “threshold point” (e.g., Max-Neef, 1995), the point beyond which more economic growth may bring about a deterioration in quality of life.

---

<sup>22</sup> Daly defines throughput in this sense as “the entropic physical flow from nature’s sources through the economy and back to nature’s sinks.”

<sup>23</sup> Max-Neef, a Chilean economist, won the “Right Livelihood Award” (also known as the “Alternative Nobel Prize”) in 1983 for his work on “human scale development” (“development as if people mattered”). He garnered almost 6 percent of the popular vote (on the “Green-Humanist” ticket) in the 1993 Chilean Presidential election.

The ISEW clearly has its weaknesses, such as the treatment of non-renewable resource depletion and the valuation of long-term environmental damage (see Neumayer, 2000), and its critics. A fundamental challenge rests on the difficulty in trying to combine the concept of well-being, which derives from the use of the current capital stock, together with the concept of sustainability, which relates to the value of the future capital stock into a single measure. In response to some of these weaknesses and as mentioned in the previous chapter, Neumayer (2003a) proposes a means to assess – at a national level – the sustainability of achieving a given level of human development by relating the UN’s Human Development Index (HDI) to estimated national levels of “genuine” or “adjusted” savings. Essentially, Neumayer’s approach allows a net capital effects “check” on levels of Human Development.

Returning to sustainable mobility, we can see the potential for adapting the ISEW or the HDI/genuine savings approach. Consider accessibility (and its role in human capital formation or as a representation of human welfare derived from the mobility system) as akin to GDP (in the beginning of the ISEW calculation) or to HDI (in the Neumayer framework). Then we can think of a sustainable mobility system as one that increases human capital (via accessibility), but not to the point where the mobility throughput required depletes our human-made, natural and social capital. Daly (2002) suggests that development “might more fruitfully be defined as more utility per unit of throughput” (p. 48); we can think of sustainable mobility in exactly the same way: *providing more utility, as measured by accessibility, per unit of throughput, as measured by mobility.*

I propose mobility as an effective measure of throughput, signifying depletion of capital stocks.<sup>24</sup> This may seem, on the surface, somewhat controversial, but all aspects of mobility imply capital stock depletion. Walking wears out shoes and consumes energy (calories). Driving a car or riding the bus implies depletion of, as examples, natural stock in the form of the resources that went into the vehicle (i.e., depreciation), the energy used (both embedded and motive), and land “consumed;” human-made stock in the form of infrastructure investments; and, social stock in terms of the dedication of institutions (e.g., for planning). The capital depletion implied by mobility throughput varies, by mode, by time of day, by occupancy levels, etc. But, we can fairly safely say that, all else equal, relative capital depletion increases with vehicle size/weight and use. This does not mean that we want to reduce total mobility, per se, as a means of minimizing stock depletion. Rather, it means that want less total mobility consumption per accessibility derived. In other words, *ceteris paribus*, walking is more sustainable than any other mode – the key, here, lying in the phrase *ceteris paribus*. For the *same level of accessibility*, walking is more sustainable than driving (or taking the bus, or biking). For motorized modes (or any mode that can be shared), occupancy plays an important role since, *ceteris paribus*, higher occupancy means more people receiving accessibility benefit at less total mobility throughput.

---

<sup>24</sup> This proposition closely aligns with Black’s (2000) observation of the need to be able to reflect the trade-off between mobility and environmental sustainability as well as Black et al (2002)’s recognition of VKT (mobility throughput) as a key (they suggest *the* key) indicator. Note that Black (2000) and Black (2002) are different authors.

We can roughly proxy mobility throughput as some weighted measure of distance traveled, with the weight representing the various capital “drains” implied by the mode. A highly fuel efficient vehicle drains fewer natural stocks, for example; an electric mode (e.g., Metro) *may* “consume” less of the airshed “stock”; etc. As an initial indicator, then, I propose vehicle distances traveled (VDT) to represent the capital drain.<sup>25</sup> VDT could subsequently be differentiated according to technology, size, even time of day of travel.<sup>26</sup> For example, if we were able to magically transform the existing vehicle fleet to one based on “carbon neutral” fuels, than the relevant capital stock drain would be reduced, making mobility more sustainable (of course, other capital stock depletion would continue). For the purposes of demonstrating the approach to measuring sustainable urban mobility and exploring it in the context of the land use-transport interaction space, I use a simple VDT measure as a proxy, recognizing that further stratification (by capital drain) of VDT impacts would certainly improve accuracy.

With the accessibility/VDT definitions in mind and returning to the ISEW framework, we could present an index of sustainable mobility in a stylized equation:

$$\text{Index of sustainable mobility} = \text{accessibility} - \text{transport consumption (VDT)}$$

Whether such an equation could actually be calculated depends, naturally, on whether the components could be measured in comparable units. Monetization seems a logical choice and in this case we see that sustainable mobility begins adhering to the “full cost school” of sustainable transportation (as mentioned in the previous chapter): a sustainable transportation system is one in which beneficiaries pay the full social costs, including those imposed on future generations (e.g., Schipper, 1996). Several controversies and difficulties lie in this path (despite some important progress; see Delucchi, 1997), not least of which might be doubts as to whether we can monetize everything. Furthermore, there are doubts about the idea of combining welfare (utility) with stocks (e.g., Neumayer, 2001; Daly, 2002). Such an approach would be in the “weak” sustainability tradition (Neumayer, 2003b).

If, instead, we draw from the HDI/genuine savings framework (e.g., Neumayer, 2003), then we can envision sustainable mobility in a “trade-off” space (see Figure III-2). From Figure III-2, we can make some relative (not absolute) judgments regarding sustainable mobility.<sup>27</sup> Assume the symbols represent individuals which might be grouped by some characteristic (e.g., neighborhood). In this case, we can say that: Group A has more sustainable mobility than Groups B, C or D; Group C has more sustainable mobility than Group D; and Group B has more sustainable mobility than Group D. This trade-off space

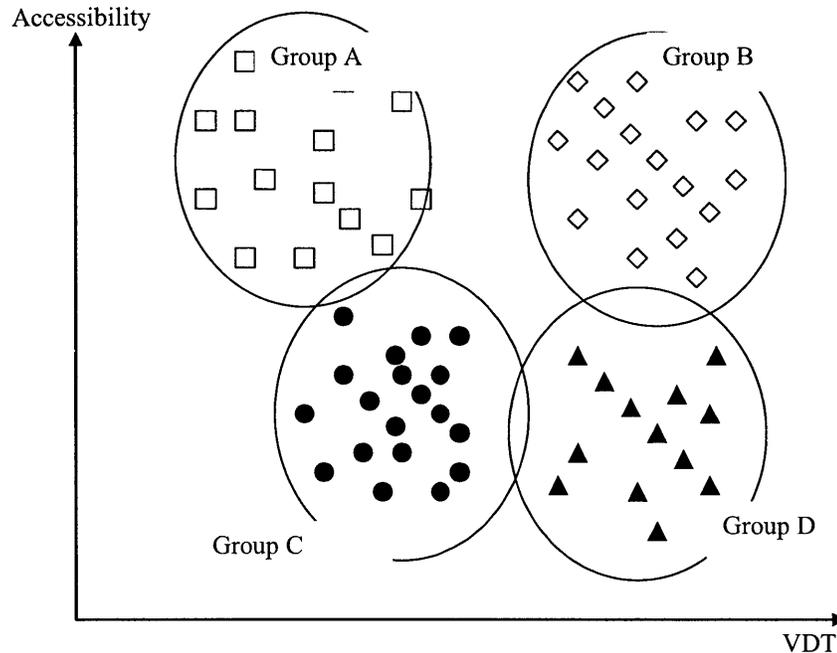
<sup>25</sup> Others have suggested and/or used vehicle distances traveled as an important indicator. McCormack et al (2001) say travel distance “is often a primary indicator of transportation activity” (p.27); Black et al (2002), in exploring indicators of transportation sustainability in Sydney, Australia, use vehicle kilometers traveled (VKT), based in part on the fact that the New South Wales Government already had VKT targets set.

<sup>26</sup> Note that the idea of the “ecological footprint” could also be used to create an index of stock drains (measured by equivalent area of land required) by stratified VDT. Barrett and Scott (2003) and Wood (2003) offer explorations along these lines.

<sup>27</sup> I thank Jinhua Zhao for the conversation that led explicitly to this framework.

offers normative guidance, telling us what is more sustainable and pointing us in the right direction. Still, a major question remains: how do we measure the benefit, the welfare, this idea of “accessibility”?

**Figure III-2. Hypothetical Sustainable Mobility “Trade-Off” Space**



### III.2 Accessibility

As mentioned in the introduction to this Chapter, accessibility measures have a long history in planning, geography and related disciplines. Not surprisingly, accessibility measures have been subject to extensive and multiple reviews over the years (e.g., Pirie, 1979; Handy and Niemeier, 1997; BTS, 1997; *Journal of Transportation and Statistics*, 2001; Geurs and Ritsema van Eck, 2001; Geurs and van Wee, 2004). The reviews often differ in their approaches to categorizing types of accessibility measures, but Geurs and van Wee (2004), summarizing a much larger research project on accessibility undertaken for the Dutch government (Geurs and Ritsema van Eck, 2001), offer a useful and comprehensive framework. Table III-3 builds off their framework and extends it to include a basic assessment regarding suitability for measuring accessibility as it relates to the sustainable mobility concept outlined in the previous section.

All of the accessibility measures have their strengths and weaknesses, depending partly on the purpose/application. Infrastructure-based accessibility measures may be perhaps the most commonly recognized, such as levels of service, etc. As discussed in the previous Chapter, such measures offer a very limited view of accessibility as understood in its broader meaning here – knowing travel times or speeds without any information on the opportunities (i.e., activities) available to travel to provides an incomplete picture of accessibility. In my proposed sustainable mobility framework, such metrics are thoroughly throughput-focused.

**Table III-3. Basic Categorization of Accessibility Measures**

<b>Accessibility Measure Type</b>	<b>Examples</b>	<b>Suitability for Measuring SM</b>
Infrastructure-based	Travel speeds by different modes; operating costs; congestion levels	Weak - only reflect level of throughput, no explicit land-use component
Location-based	Distance measures (e.g., cumulative opportunities); potential measures (e.g, gravity-based measures); balancing factor measures (i.e., from the doubly constrained spatial interaction model)	Okay/Good - normally derived for some spatially aggregated unit; can represent stratified population segments
Person-based	Space-time prisms	Good - measured at the individual level, according to temporal constraints
Utility-based	Random utility-based measures (i.e., from discrete choice models or the doubly constrained entropy model)	Good - based on microeconomic benefit (utility) for individuals or stratified population segments

Source: Extended from Geurs and van Wee, 2004.

Among the location-based measures, the distance measures are fairly straightforward, essentially capturing the number of opportunities that can be reached within a given distance (or time or cost) (see Ingram, 1971; Wachs and Kumagai, 1973; Allen et al, 1993). At the same time, their simplicity makes them a weak candidate for measuring accessibility in a sustainability framework, in part because they cannot really account for individuals' preferences and because of their sensitivity to the not necessarily behaviorally-rigorous distance/friction/cost parameter. The gravity-based models, which find their theoretical origins in physics, offer an improvement over distance-based measures, partly because they attempt to better reflect travel behavior realities through their functional form, generally:

$$A_i = \sum_j \frac{W_j}{f(c_{ij}, \beta)} \quad (3.1),$$

where:

- $W_j$  represents the opportunities available in a given zone j;
- $f(c_{ij}, \beta)$  represents impedance between zones i and j;
- $c_{ij}$  represents the travel cost/distance between zones i and j; and
- $\beta$  is a travel cost sensitivity parameter.

The cost/distance sensitivity parameter,  $\beta$ , generally enters as a negative exponential function and the accessibility measure clearly is highly sensitive to this parameter. This parameter should come from empirical analysis (resulting, e.g., from trip origin-destination matrices). The gravity-based approach more closely fulfills the sustainability requirements of an accessibility measure, providing the possibility to measure for an area

(zone) and/or groups of people and can also be calculated fairly easily from travel survey data. Furthermore, gravity-based models have been adapted to deal with an important potential source of inaccuracy in accessibility measures: the failure to account for potential competition for opportunities at the destination (e.g., when the number of job opportunities is limited at given site). Shen (1998) offers one example of a way to incorporate competition effects in a gravity model (see, also, Harris, 2001). Competition effects are explicitly accounted for in the third location-based accessibility measure (which, in form, is similar to the gravity model): the balancing factors from the doubly constrained spatial interaction model (e.g., Williams, 1976). The difficulty in calculating and interpreting this latter measure may, at least partly, account for its infrequent use (Geurs and van Wee, 2004).

What Geurs and van Wee (2004) call “person-based,” others (e.g., Baradaran and Ramjerdi, 2001) have referred to as the “constraints-based” accessibility approach. The approach originates in Hagerstrand’s (1970) time-space framework and aims to capture the temporal and spatial constraints that individuals face. In other words, constraints on people’s accessibility come not only from distance (between themselves and potential activities), but also from the amount of time they have to engage in those activities. The available time clearly is, in part, a function of the transport system performance (time to reach desired activities). While theoretically appealing and not without example applications (see Pirie (1979) for a review of an early approach), the time-space derived accessibility measures suffer from their data-hunger (e.g., they require information on people’s activities and time budgets) and their computational difficulties.

### **III.2.1 Utility-Based Measures**

The attractiveness of “utility-based” accessibility measures come from their direct link to individual utility (welfare). Utility-derived accessibility measures come from discrete choice models, widely applied in transportation system analyses (e.g., to predict a consumer’s choice from among different travel modes). The advantage of utility-based accessibility measures is that they can reflect individual preferences (consistent with Sen’s “human freedoms” perspective; Table III-2), can be measured for the individual (based on the individual’s actual choice) and are directly linked to traditional measures of consumer surplus (e.g., Williams, 1977; Small and Rosen, 1981). This provides a direct link to the welfare-based definition of sustainable mobility presented above (Section III.1.1). This derivation of an accessibility measure from disaggregate discrete choice models can be traced back to Ben-Akiva’s (1973) seminal dissertation on travel demand models and Williams’ (1977) explicit derivation of economic benefit (consistent with random utility theory), giving central importance to composite costs (or inclusive value or inclusive prices) (see Ortúzar (2001) for a brief history on these models’ origins). In 1979, Ben-Akiva and Lerman (1979) explicitly link the disaggregate discrete choice modeling framework to the accessibility concept, enabling a direct relationship to individual choice based on that individual’s choice set. Specifically, they offer a definition of accessibility as “simply the utility of the choice situation to the individual” (p. 656). In practical terms, since utility is random (hence the “random utility” label given to discrete choice models) and not directly measurable, Ben-Akiva and Lerman

(1979) suggest the expected maximum utility (e.g., the denominator of the logit model) as a “reasonable alternative.”

The utility-based accessibility measures rest on the assumption that people select, from a set of alternatives, the choice that provides the highest utility. Because we cannot actually know the utility level, we treat it as a random variable (thus “random utility” theory). The utility,  $U$ , then, to individuals  $n$  for alternatives  $j$ , is comprised of two, additive components:

$$U_{jn} = V(z_{jn}, s_n, \beta) + \varepsilon_{jn} \quad (3.2),$$

where  $V$  represents a systematic utility function,  $z_{jn}$  is a vector of attributes of the alternatives  $j$  for decision-maker  $n$ ,  $s_n$  is a vector of socioeconomic and/or demographic characteristics of the choice-maker,  $\beta$  is a vector of unknown parameters and  $\varepsilon_{jn}$  represents the unobservable, unknown portion (i.e., the random “disturbance”) of utility. Since we cannot measure everything relevant to the individual’s decision, the choice is probabilistic.<sup>28</sup> In the widely familiar *logit* model of choice, the error term is assumed to take on an identical, independent distribution (IID), that is also Gumbel-distributed with a scale parameter,  $\mu$ .<sup>29</sup> The resulting, basic probability framework becomes:

$$P_n(i) = \frac{e^{\mu V_{in}}}{\sum_{j=1}^J e^{\mu V_{jn}}} \quad (3.3).$$

In equation (3.3), the probability that individual,  $n$ , chooses alternative,  $i$ , is based on the systematic utility,  $V$ , of  $i$  for chooser  $n$ , relative to the systematic utilities of the all the relevant alternatives,  $V_{jn}$ . The most common functional form for  $V$  is linear in the unknown parameters ( $\beta$  in 3.2) (it can still be nonlinear in any given set of independent variables). In this case, the scale parameter,  $\mu$ , cannot be distinguished from the scale of the  $\beta$ ’s, which requires an arbitrary assumption about the value of  $\mu$ . For convenience, the typical practice in the logit approach is to normalize this value to 1.

The assumptions of the logit model introduce important restrictions. In particular, the IID assumption means that all the disturbances have to have the same scale parameter; in other words the variances of the random (non-systematic) utility components are equal. The mutual independence of the disturbances also rests at the core of the key multinomial logit (MNL) property: the independence of irrelevant alternatives (IIA). The IIA property signifies that, for any individual, the probability of choosing among any two alternatives depends only on the relevant utilities (of the two alternatives) and is not affected by the systematic utilities of other alternatives. This assumption can be highly restrictive for modeling actual choice processes, particularly when choices’ random utilities (the

<sup>28</sup> The choice probability is  $P_{in} = \text{Prob} [U_{in} > U_{jn} \text{ for all } j \neq i] \rightarrow = \text{Prob} [V_{jn} + \varepsilon_{jn} < V_{in} + \varepsilon_{in} \text{ for all } j \neq i] \rightarrow = \text{Prob} [\varepsilon_{jn} - \varepsilon_{in} < V_{in} - V_{jn} \text{ for all } j \neq i]$ .

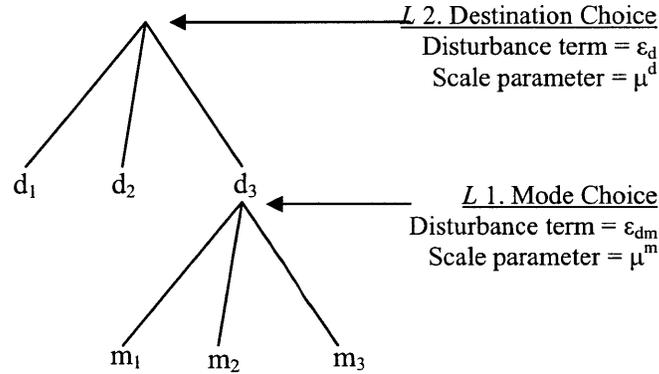
<sup>29</sup> The distribution is defined by:  $\text{Prob} [\varepsilon_{jn} < x] = \exp(-e^{-\mu x})$  for all real numbers,  $x$  and where, again,  $\mu$  is a scale parameter.

“disturbances”) are correlated, which would violate the IIA property. A more generalized logit form that relaxes the IIA restriction takes on a “nested” form, in which the members of choices within a “nest” are allowed to have correlated error terms, while the error terms across “nests” (or groups of alternatives with correlated error terms) remain subjected to the IIA assumption. A nest might consist of, for example, different public transport modes.

### III.2.1.1 Nested Logit: Basic Theory and Model Structure

The nested logit generalization of the MNL model structures the choice process in a joint fashion, whereby decision-makers choose alternatives from within groups of possible outcomes. Examples include the choice of where to travel, what mode to take, and what route to take or more complex choice processes which might also add the choice of whether to travel and, e.g., what time to travel. Figure III-3 depicts a simple two-level example of the decision tree of where to travel (destination choice) and the mode to travel by (mode choice). The decision process does not represent a sequential process, per se, but shows the pattern of similarities within a decision process that is simultaneous (e.g., Small and Winston, 1999). In other words, in the depiction in Figure III-3, the traveler views all of the different modes for traveling to destination 3 ( $d_3$ ) as more similar to each other than all of the destinations that one can choose to go to by mode 3 ( $m_3$ ). In this example, the lower level (mode choice) has the error term  $\epsilon_{dm}$ , with scale parameter,  $\mu^m$ , while the upper level contains the total error,  $\epsilon_d$ , with scale parameter,  $\mu^d$ .

**Figure III-3. Basic Depiction of a Two Level Nested Logit Travel Decision**



The choice process depicted in Figure III-3 can be represented by the basic choice model (e.g., Ben-Akiva and Lerman, 1985):

$$P_n(dm) = P_n(m|d)P_n(d) \quad (3.4),$$

where:

$$P_n(m|d) = \frac{e^{(V_m + V_{dm})\mu^m}}{\sum_{m \in M_{nd}} e^{(V_m + V_{dm})\mu^m}} \quad (3.5),$$

$$P_n(d) = \frac{e^{(V_d + V'_d)\mu^d}}{\sum_{d \in D_n} e^{(V_d + V'_d)\mu^d}} \quad (3.6),$$

and where:

$$V'_d = \frac{1}{\mu^m} \ln \sum_{m \in M_{nd}} e^{(V_m + V_{dm})\mu^m} \quad (3.7).$$

The last equation (3.7) shows the explicit link between the two nest levels. In this case, the utility from the mode choice model figures directly into the utility function for the destination choice model. In other words, the systematic utilities of the lower level decision (the mode chosen to get to the particular destination) figure into the utility of the destination choice. Equation (3.7) comes from the denominator of the lower level choice (the mode choice in this case) and is the term which is also known as the “inclusive value” or the “logsum” (from its form). This term represents the expected maximum utility achieved from the relevant set of alternatives, i.e.:

$$E(\max_{i \in C_n} U_{in}) = \frac{1}{\mu} \ln \sum_{i \in C_n} e^{\mu V_{in}} \quad (3.8),$$

where  $V_{in}$  is the systematic component of utility  $U_{in}$  for individual  $n$  choosing one alternative from the choice set  $C_n$ .<sup>30</sup> This term (3.8) serves as a summary measure or index of the utility of the entire choice set to the chooser and is directly connected to conventional welfare measures (e.g., Small and Rosen, 1981). This is also the term that Ben-Akiva and Lerman (1979; see also 1985) call a “measure of accessibility.” As suggested in Figure III-3 and shown in equations (3.5)-(3.7), in the case of the more general nested logit model (NL), the logsums “pass up” the model chain, with the logsums from the lower levels being included within the utility component of higher levels, up to the root, or highest level. The logsum calculated for the root (also referred to as the “composite utility”) represents the expected value to the individual of the full choice set; in Figure III-3 and equations (3.5) to (3.7), the root logsum would be calculated from the denominator from the destination choice model (equation 3.7), which includes the logsum (“inclusive value”) from the mode choice model. In this way, the utility to the individual includes the utilities deriving from the modes of travel to get to a given destination and the destination itself.

In the nested logit framework, the scaling parameter,  $\mu$ , takes on important relevance because more than one unknown scale parameter exist, one for each nest level (e.g., in Figure III-3,  $\mu^m$  and  $\mu^d$ ). Generally, then, one of the nest levels needs to be “normalized,”

---

<sup>30</sup> Equation (3.8) can be generalized to the Generalized Extreme Value (GEV) model (of which MNL and NL are special cases):  $E(\max_{i \in C_n} U_{in}) = \frac{1}{\mu} \ln G$ , where  $G$  is the function representing the particular form of the GEV model (e.g., Ben-Akiva and Lerman, 1985).

typically to one, in order to make the other level's estimated coefficients identifiable. In recent years, considerable debate has surrounded the implications of normalization, with particular concern for implications on utility maximization principles. Carrasco and Ortúzar (2002) show that either upper or lower level normalization is consistent with utility maximization, although they point to several reasons to prefer the upper-level normalization. In practice, particularly for multi-dimensional choice models such as the destination and mode choice depicted in Figure III-3, lower level normalization may be required, in order to be able to estimate the logsum values for inclusion in the upper nest calculations. When this is done in a sequential process (for a clear overview of the procedure, see Ben-Akiva and Lerman (1985; pp. 295-299), with normalization on the lower nest, the standard errors of the coefficients' estimates on the upper nest will be biased downwards (meaning the model estimates will be consistent, but not efficient).<sup>31</sup> To be consistent with theory, the parameter value estimated on the lower level logsum value included in the upper level nest should be between 0 and 1.

### *III.2.1.2 Interpreting Utility-Based Logsum Measures*

A practical challenge to utilizing logsum-derived accessibility measure comes from the fact that the expected maximum utility (equation 3.8) is not, generally, in a form directly comparable across individuals. To make such measures comparable, both the scale and level conditions must be satisfied (for more detail, see Dong et al, 2005). The scale condition refers to the fact that the accessibility units implied in the logsum vary across individuals. The level condition refers to the fact that the logsum-based accessibility measures need to have a consistent benchmark utility; this is because the expected absolute size of the utility – which depends on, for example, arbitrary decisions regarding utility specification (such as to indicate male [or female] by a dummy variable equal to one [or zero]) – can change the accessibility value (as calculated by equation 3.8). Such conditions require that the accessibility measure be normalized to meet both the scale and level conditions. The level condition can be satisfied by, for example, calculating the differences in accessibility produced by changes from a specific policy scenario. The scale condition can be satisfied by converting the accessibility measure from the generic “utility” units into the units of one of the model variables (typically using time or money). The resulting normalized accessibility measure can then be directly compared across individuals. An alternative approach to viewing differences in accessibility levels across an urban area is to compare relative accessibility levels for a representative individual (e.g, middle income male) if that individual were located in different parts of the city (again, for more detail and example applications see Dong et al, 2005). The latter approach is employed in the empirical application in Chapter IX.

Logsum accessibility measures have been calculated, for example, from mode choice models (by Weisbrod, et al. (1980) to value accessibility in a multi-stage model to explain moving and residential location choice), for the combined mode-destination choice (e.g., Niemeier, 1997; Limanond and Niemeier, 2003) and the destination choice (e.g., Srour, et al., 2002). An interesting linked utility-based trip frequency choice (count regression) and destination choice model (as an MNL and NL) applied to the decision to

---

<sup>31</sup> The size of the error of the standard errors diminishes with increased sample size (Ben-Akiva and Lerman, 1985).

make recreation trips and where to make them (applied to inter-urban trips) provides an analogous structure to calculating travel benefit in a utility-consistent way (Hausman et al., 1995). Hunt (2003) reports on a “quasi” nested logit model (trip generation-destination choice-time period choice-mode choice-route choice) for the city of Edmonton in which the composite utility of travel fed up to the trip destination choice provides the measure of aggregate mobility benefits. Recently, Martínez (1995) and Martínez and Araya (2000a) directly link utility-based accessibility measures to the doubly constrained entropy model (i.e., spatial interaction model), which provides the further benefit of accounting for competition effects or other constraints on destination choice.

The utility-based measures provide theoretical appeal (e.g., basis in behavioral theory and welfare economics) and the resultant accessibility measures can be converted into meaningful and readily understandable units (e.g., currency, minutes).<sup>32</sup> Shortcomings include the assumptions of utility being linear with respect to income (i.e., nonpresence of income effect); furthermore, some fundamental philosophical questions can be raised about the assumption of rational “utility-maximizing” behavior.<sup>33</sup> In addition, when measured from *travel* models, utility-based accessibility measures will be naturally biased towards valuing trip-making in the sustainability “equation.” For example, someone who simply elects not to make trips (for example, by combining multiple trip purposes into a trip chain or replacing a trip via telecommunication) would, in the trip-based approach, have a lower accessibility measure, even though she did not necessarily experience any actual decline in welfare.

Some explorations have been made which would help address the latter shortcoming, basically through a merging of the person-based (time-space) approach with the utility-based approach (Baradaran and Ramjerdi (2001) refer to this as the “composite approach”). Basically, this is the “activity-based” approach which, essentially, aims to measure the benefits associated with people’s activities throughout the day. The “cutting edge” of travel behavior research has already embraced this direction, and some explorations in deriving “activity-based” accessibility measures in the discrete choice random utility framework have been made. In particular, Dong et al (2005) take the conceptual approach one step further (and, in rigor, move closest to an accessibility-benefit measure not inherently biased towards mobility), by presenting and estimating an activity-based (as opposed to trip-based) accessibility measure, deriving the logsum value by examining an individual’s choice to undertake all trips and activities throughout a day (providing, as such, an accessibility measure that is not mobility-biased, effectively accounting for the fact that those individuals who choose not to make a trip may not necessarily suffer from lower accessibility). Despite their theoretical attraction, the activity-based measures are still quite data hungry.

---

<sup>32</sup> Although their derivation from random utility theory may complicate their communicability to laypersons.

<sup>33</sup> Tanimura (2004) quotes the Japanese philosopher Shunsuke Tsurumi’s concept of “pleasure with intentional inconsistency,” which one can interpret to mean that people may well derive pleasure from random variety, not some quest for a single, most optimum solution.

### III.2.1.3 Final Remarks on Accessibility Measures

Ultimately, no universally-agreed upon criteria exist for determining the “best” accessibility measure, particularly in the proposed sustainable mobility framework. Generally, Ramming (1994) recommends that an accessibility measure should: reflect different preferences among people, address scarcity (of people’s time and money), and reflect some measure of *potential* travel. These criteria – entirely consistent with the SM framework – clearly point to an activity-based measure. Bhat et al (2000) outline the attributes of an “ideal” accessibility measure, by identifying characteristics in three areas, those related to: “impedance” (i.e., travel, itself), including safety, convenience, comfort, aesthetics; the destination, including, again, safety, convenience, aesthetics, etc.; and the traveler, including vehicle availability, age, disability status. Discrete choice models can satisfy these needs. Finally, Geurs and van Wee (2004) highlight the need for an accessibility measure to capture all relevant accessibility components (land use, transportation, the individual, and temporal; similar to Bhat et al (2000), except for explicit inclusion of the temporal aspect in the time-space constraint tradition) and further add that the measure needs to meet some degree of “operationalization” and be interpretable and easily communicated. Based on these criteria, no accessibility measure would be perfect; while the composite, activity-based approach approaches the theoretical ideal. As suggested in Table III-3 and in the discussion above, the utility-based measure offers a decent measure and it is the one ultimately adopted in the empirical application in Chapter IX.

### III.2.2 Accessibility and Travel Demand: An Indicator or Variable?

As accessibility can be defined in many ways, estimated in many ways, and assessed in many ways, it can also be used in many ways. An important distinction needs to be made, however, in the use of accessibility in the understanding of travel behavior: the derivation of accessibility as an indicator (e.g., an output) to compare, for example, different cases; its use as a variable (i.e., as an input) in analyses; and/or the combination of the two (including iteratively).

When accessibility is used as an input, the purpose is essentially as a determinant of some behavior or activity, but not, ultimately, as a meaningful measure on its own. In this case, accessibility is generally taken as a variable influencing, for example, residential choice, or mode choice, or trip choice. Levine (1998), for example, uses a household’s worker(s) commute time(s) as an “accessibility” variable influencing residential choice. Many of the studies aiming to understand the influence of urban form (or the built environment or land use) on travel behavior (reviewed in the following Chapter), utilize “accessibility” measures in this way.<sup>34</sup> Examples include: Greenwald (2003), e.g., distance to bus stops; Krizek (2003), e.g., “neighborhood accessibility”; Hess and Ong (2002), e.g., “transit accessibility”; Holtzclaw et al. (2002), e.g., number of jobs within certain driving distance; Boarnet and Crane (2001a), e.g., distance to CBD; Miller and Ibrahim (1998), e.g., employment density within certain radii; and Hanson (1982), e.g., number of establishments within various radii of home. “Logsum” (see Section III.2) accessibility

---

<sup>34</sup> Note, they are not always referred to as “accessibility” measures; even population density or share of commercial space in a given zone is, technically, an “accessibility” measure in the distance-based sense, as it is an inherent indication of the relative nearness of people, stores, etc.

measures can also be used in this sense, such as in models of residential location choice (e.g., Srour et al, 2002) or of vehicle ownership and use decisions (e.g., Kitamura et al, 2001).

On the “output” side, the aim is to derive accessibility as an indicator. For example, Allen et al (1993) measure accessibility across US cities as an output, basically, of road system performance.<sup>35</sup> Niemeier (1997) uses the “logsum” approach to measure individual accessibility benefits as the outcome of the mode-destination choice for the AM journey to work. Limanond and Niemeier (2003) also use the “logsum” approach to measure variations in neighborhood accessibility. Martínez and Araya (2000b) demonstrate the calculation of total user benefits due to accessibility changes in a land use-transportation interaction framework (a doubly constrained entropy model).<sup>36</sup> My proposed measure for sustainable mobility uses accessibility in this sense: as an *output* of individuals’ choices in the land use and transportation system: indeed, as an attempted measure of the individuals’ *benefit* from this system.

### III.2.3 Accessibility as an Indicator for Sustainable Mobility

Despite its common use in research and fairly common use in relevant official rhetoric, accessibility does not find much currency as a formal performance measure for authorities. Bhat et al (2000), in an initial assessment of accessibility measures and their potential for development as performance measures in large Texas cities, found limited examples of their use. Among U.S. states or cities, they found that Oregon uses the logsum from the mode choice model as a performance measure and Albany (NY) uses travel time between “representative locations” in their congestion management system. One other state (Florida) and two other localities (Albuquerque, NM and Greater Los Angeles) had recommendations or case studies to develop accessibility-type measures (e.g., cumulative opportunities). They also found a pilot program in the Netherlands, aiming to derive metrics based on network distances (e.g., to public transport nodes and major road infrastructure).<sup>37</sup> Finally, Bhat et al (2000) note that the United Kingdom includes several specific accessibility performance measures, primarily aimed at assessing public transport levels of service.

Accessibility actually appears as one of five of the UK Central Government’s transport objectives: environment, safety, economy, accessibility and integration. And, in terms of a specific performance measure, the UK includes accessibility as an objective in its “New Approach to Appraisal: Appraisal Summary Table (AST)” (ECMT, 2004). The current version of the AST comes from the UK Government’s Guidance on the Methodology for Multi-Modal Studies (GOMMMS) which was issued in 2000. Within the accessibility “objective,” the AST includes 3 categories: access to the transport system (for those with no car available); “option values” (the value of having an alternative mode available);

---

<sup>35</sup> Allen et al do, however, go on to use this accessibility indicator, measured in minutes, as a variable (input) to a model to predict employment growth patterns across cities.

<sup>36</sup> In rigor, in the integrated model, the accessibility (and attractions) calculated are inputs (to one time period) and outputs of the next.

<sup>37</sup> Note that the major review of accessibility measures and pilot applications carried out by Geurs and Ritsema van Eck (2001) was conducted for the Dutch Government, under a project called “Evaluation Methodology for Transport Scenarios.”

and severance (due to infrastructure impeding pedestrian travel). The recommendations suggest qualitative assessment criteria for these categories, and they consider that cost benefit analysis takes into account “most aspects of accessibility” (UK CFIT, 2004, p. 37). The perceived difficulty in estimating accessibility within UK appraisal frameworks is indicated by a review of appraisal techniques applied to a road project, in which it was judged that techniques for estimating “accessibility” “are fairly crude” compared to cost-benefit analysis, which might lead to decision-makers not focusing on these criteria (ECMT, 2004, p. 177).

As mentioned in the previous chapter, the concept of accessibility or access appears in many definitions of sustainable transportation or sustainable mobility. Drawing from Jeon and Amekudzi’s (2005) review of 16 “practitioner and research initiatives on transportation sustainability,”<sup>38</sup> five make specific reference to access or accessibility in their definitions. Among the nearly 180 indicators listed for at least one of the 16 initiatives, at least ten can be related to the accessibility measures outlined above (i.e, as distance-based measures, potential measures, etc.). One project explicitly includes an “accessibility measure” – the PROSPECTS project funded by the European Commission. A forecasting project, looking to assess sustainable transportation in several European cities under various policies, PROSPECTS reports on some efforts to calculate logsum accessibility benefits from integrated land use transport models along the lines of Martínez and Araya (2000b) (Minken et al, 2003). The PROSPECTS guidebook mentions the work of Geurs and Ritsema van Eck (2001) as a potential source of guidance for calculating accessibility measures.

Notably, the World Business Council for Sustainable Development (WBCSD) leads off its Sustainable Mobility Full Report (2004) with accessibility as its first indicator. The WBCSD recognizes the challenges to measuring accessibility and the fact that rarely is it measured. Then – in a move that a cynic might view as opportunistic – they claim that “Almost universally ‘accessibility’ is defined as ‘access to the means of personal mobility’” and go on to suggest household motor vehicle ownership and distance to a “minimum quality” public transport as “a way ahead” (pp. 18-19). The inadequacy of this proposed metric in light of the discussion in the previous section should be self-evident.

Finally, Kwok and Yeh (2004) propose the modal accessibility gap (MAG) as an indicator of sustainable mobility and demonstrate its application in Hong Kong. While in some ways analogous to the approach proposed here, the MAG has some problems. First, it begins with a presumption that public transport is more sustainable the private transport, which may (or may not) be the case. This presumption, nonetheless, defines the metric, which in turn fails to enable the discrimination between benefit (welfare) and cost (capital drain). Furthermore, their use of a generic gravity-based accessibility metric does not allow for differentiation between individual preferences, trip purposes, etc.

---

<sup>38</sup> It is not very clear how the authors arrived at these 16 initiatives; they range from government performance plans, NGO projects and papers, international agency guidance, and case studies; not all of them appear to be, necessarily specific to transportation (e.g., World Bank Environmental Performance Indicators manual).

### III.3 Accessibility, Travel Demand, and Mobility

To put all this in perspective and close out this chapter, we bring the accessibility discussion back into the broader mobility context. Mobility can very often increase accessibility; the desire to increase accessibility (to more and/or better activities) is, then, a fundamental underlying driver of personal travel demand. One can expect increasing income levels to naturally fuel increases in accessibility demand and, thus, mobility demand. Other key drivers of passenger transport demand worldwide (as measured by distances traveled) are (e.g., RAND Europe et al, 2003) urban decentralization (i.e., suburbanization), increasing labor force participation, and declining household size (which will lead to higher motorization rates and some increasing per capita trip rates as people realize more out of home socializing). The basic results are more trips, longer trips, and more trips by automobile.

Without doubt, considerable variation exists within this broad-brushed global dynamic. Cultural factors may influence, for example, bicycle use. Legacy systems (built urban form and densities; public transport systems) will influence public transport patronage. Some countries and cities (mostly in Asia) display a much higher propensity for motorized two-wheelers. But, in general we can expect to see an increase in the number and length of trips. This will particularly be the case in the developing countries, with relatively low private vehicle mobility levels (and relatively low accessibility levels), we logically expect much more rapid growth in vehicle ownership and use. By one estimate, over the next 50 years per capita light duty VDT in the OECD countries will increase in the range of 0.2 to 0.8 percent per year, as compared to nearly 6 percent in China, 5 percent in India, and almost 3 percent in Latin America.<sup>39</sup> Clearly, these rapid growth rates signify an important amount of “catching up” – the projections suggest that in the year 2050 private VDT per capita in North America will still be 3 times higher than in Latin America (compared to levels 11 times higher in 2000).

This projected mobility growth reflects the fundamental benefit of accessibility, which is clearly what economists would call a “superior” good, as reflected, for example in apparent willingness to pay. Across a spectrum of countries, transportation represents anywhere in the range of 8 to 20 percent of household expenditures (e.g., Statistics New Zealand, 2003; Transport Canada, 1998; U.S. FHWA, 2002). The share often tends to increase with income; some suggest that this reflects a modal “trap” (e.g., STPP, 2005), but this also reflects value (households elect to spend on transportation because of the benefits it gives them in terms of choice of residence, choice of destinations, etc.). I do not intend to enter into that debate here; the important point, in the context of developing countries and sustainable mobility, is the lack of accessibility many residents in these countries suffer from. The World Bank (2002) characterizes the transport condition of the poor in multiple dimensions: “accessibility poor,” i.e., restricted to whatever is nearby; “time poor,” since they suffer the slow modes; safety poor, since they are exposed to accidents and personal security risks; and finally “energy poor,” since they have to expend a lot of energy (physical and mental) for their travel drudgery.

---

<sup>39</sup> Derived from IEA (2004).

Ultimately, a number of interacting forces play a role in exacerbating the mobility and accessibility conditions of the poor. Peripheral settlements, a product of cheap land and housing pressures, often imply isolated developments with few nearby amenities and long work trips (to jobs often located in high income areas). Gender issues can pose major problems in developing cities, particularly among the poor. Women generally have less access to private vehicles (even if there is one in the house) and their travel habits – often related to household maintenance – will not be conducive to convenient public transport itineraries. They further suffer possible dangers on public transport.

Clearly, the developing world needs to increase residents' income levels, and improve income distribution. With these increases we will expect increased mobility demand, increased motorization and increased sustainability benefits (higher accessibility) and costs (more mobility). We will also expect a large share of future mobility demand to occur in the form of discretionary travel (i.e., non-work, non-school), which in some cases already accounts for a large share of total travel (such as more than 20% of trips in several African cities; e.g., Godard and Díaz Olvera, 2000).

Finally, while we have characterized accessibility as the *raison d'être* of passenger travel, that is not entirely the case. The mobility-for-accessibility perspective implies a largely utilitarian perspective – we travel to derive accessibility, thus the oft-used “travel is a derived demand.” Travel is not, however, always a “means” to an “end,” but is, sometimes, the “end” itself. Much research has focused recently on this phenomena; Ory and Mokhtarian (2005), for example, in a recent study of San Francisco Bay Area folks found evidence of “travel liking” (e.g., due to adventure, variety, independence desires, etc.) and not just for leisure trips, but for routine trips and not just for auto use. Arentze and Timmermans (2005) find evidence of the use of extra travel as a means of “information gain” (i.e., better information on products, space, etc.) Of course, the function of travel in social class formation cannot be ignored either; that is, the idea of the car as a status symbol, well beyond a utilitarian object. In this vein, Vasconcellos (1997) details the car as a critical apparatus in the “making of the middle class.” At the same time, almost the opposite can be said, in many cases, for other modes; the bicycle (and even public transport) is often stigmatized as the mode of the poor, for example.

### **III.4 Conclusions**

Building from relevant literature, this Chapter makes four basic contributions. First, it proposes an operational definition of sustainability mobility as *maintaining the capability to provide non-declining accessibility in time*. This is a straightforward, simple, but not necessarily obvious definition. The chapter then proposes a metric for measuring the concept, drawing from accessibility measures in relevant disciplines, and explicitly recognizing mobility as a throughput (i.e., capital depleting). All else equal, we want more accessibility with less mobility throughput. The Chapter continues with a discussion of the definition and the proposed metric within the context of relevant analyses. The proposed metric, fitting into performance-based transportation planning approaches, represents something of a *paradigm shift*. Finally, the Chapter concludes by considering the relevance of the proposal within the accessibility/mobility poor developing world.

## IV

### THE BUILT ENVIRONMENT, MOBILITY & ACCESSIBILITY

As discussed in the last Chapter, accessibility is influenced by the transportation system, the land use system, as well as the individuals in that system. Via planning, we can influence the built space (the land use and the transport system) and, indirectly then, people's use of time. To what degree can we shape cities to produce changes in individual's behavior within the land use-transportation system? Not surprisingly, over the past fifty years, a considerable share of analytical effort has focused on this question. This Chapter reviews the relevant research.

#### IV.1 Introduction

Analyses of the influence of urban development patterns on travel behavior can be traced back to the beginnings of the modern practice of transportation engineering. For many years the task was predominantly “predictive” – predicting where land development would occur, estimating the associated travel demand, and providing the necessary infrastructure. For example, an early review of metropolitan transportation studies in the United States focused on the relationship between population density and transportation system requirements, aiming to assess how urban growth patterns influence travel demand and transport system needs; the analysis provides no mention, however, of how densities might be used to produce desired transportation outcomes (Levinson and Wynn, 1963).

Nonetheless, evidence of a “prescriptive” focus<sup>40</sup> (i.e., land use as a transport strategy) can be found in at least the early 1950s. For example, Carroll (1952) looking, basically, at the jobs-housing balance in several *still*-industrial U.S. cities, concludes with a call for “cohesive satellite development” of urban areas as part of a strategy to reduce the quantity of work travel, thereby “attacking the traffic problem at the most effective point” (p. 282). An analysis (Adams, 1959) of travel surveys conducted from 1948-1953 in 30 US cities, aimed to understand the factors influencing public transportation and automobile use and included the influence of land use “distribution” factors (crudely measured due to lack of computing power, but similar in concept to the types of variables still in use today). In the Netherlands, explicit policies using spatial planning to influence travel behavior began in the 1960s (Maat, et al., 2005). In the late 1960s, with the advent of large scale modeling of the relationships between land use and transportation, came several analyses of hypothetical cities aiming to gauge the influence of various structural differences in urban form (e.g., linear versus “cartwheel;” see Jamieson et al., 1967) on transport costs. The early 1970s, at least in part spurred by the energy crisis, saw a growing number of relevant studies in the United States, both simulation- and empirically-based (Gilbert and Dajani (1974) provide a review). At that time, some analysts were already calling for restructuring cities in the U.S. – expressing concern over the development patterns of the previous thirty years and calling for a focus on multi-centric urban development, with a “proximity” focus and the promotion of non-motorized

---

<sup>40</sup> Boarnet and Crane (2001a) explicitly pose the “predictive” versus “prescriptive” perspectives, but without specific contextual history of relevant analyses.

transport (Orski, 1974).<sup>41</sup> Simulation and empirical comparative studies continued to be developed in the 1970s and into the 1980s (e.g., Edwards and Schofer, 1976; Cheslow and Neels, 1980; Small, 1980; Kim and Schneider, 1985). At this time, as discussed in Chapter II, the idea of the “sustainable city” and “sustainable transport” begin seeping into relevant discourses.

This growth in interest of a potentially “prescriptive” role for land planning to address transport ills parallels, to some degree, urban planning theory, policies, and patterns, particularly in the Post-WWII United States (and, indeed, the modernist approach to planning discussed in Chapter II). Howard’s “Garden City” model, emerging at the beginning of the 20<sup>th</sup> Century, had an implicit transportation-orientation, aiming to create self-contained and walkable communities. The first large scale attempt to fully adapt the “Garden City” model in the U.S. – Radburn (New Jersey), built just before the Depression in 1928 – aimed to promote pedestrian travel while accommodating rapidly growing automobile usage (Lee and Ahn, 2003). This aspect of the Radburn design principles was largely lost in subsequent mass adaptation of its cul-de-sac and curvilinear street networks to the rapidly suburbanizing country (Zhang, 2004). Partly in response to a growing “suburban critique,” aimed in some sense towards true adherence to Howard’s “garden city” concept, and – perhaps most practically – driven by large landowners and capital sources, the “new community” movement blossomed in the U.S. in the 1960s, including through Federal legislation and policy (Weaver, 1965; Burby, et al., 1976).<sup>42</sup> Epitomized by places such as Columbia, Maryland, the “new community” movement aimed to overcome the criticisms of haphazard suburban growth, including its aesthetic, environmental, functional, and social (e.g., lack of social institutions, individual “isolation) impacts (see Burby, et al., 1976). The approach embraced large scale development (i.e., at least 2,000 acres and 20,000 persons) as a comprehensive suburban antidote and included explicit transportation-oriented benefits, again primarily by aspiring towards self-contained communities (see, e.g., Morris, 1969; Zehner, 1977).<sup>43</sup> By the early 1970s, even the financial industry showed some concern for the environmental effects related to traditional sprawling development patterns.<sup>44</sup> By the

---

<sup>41</sup> Today Orski appears much less sanguine about the possibilities for restructuring urban form as a viable means to reduce travel demand in the U.S (see, e.g., Orski, 1999).

<sup>42</sup> This quote from the Administrator of the U.S. Federal Housing and Home Finance Agency in 1965 could have easily been written today: “the critical relationships between transportation systems and land uses must be carefully thought out before it is too late. We have made too many mistakes in the past to be able to afford more. There are alternatives to sprawl and unguided metropolitan growth...corridor patterns, satellite cities, clusters of semi-urbs...” (Weaver, 1965; p. 4).

<sup>43</sup> Note, however, that the new town/new community movement was not specifically aimed at reducing automobile traffic, per se. In fact, Morris (1969) suggests that the new town “makes freeways feasible for substantially lower volumes than those considered in existing cities” (p. 107); he suggests the main barrier to providing infrastructure at such high standards (e.g., “no delays to traffic by congestion at peak hour *at the turn of the century* when *motor car ownership* will have reached, or nearly reached *saturation*.” [emphasis added]; p. 108) is the fact that the private sector developers have to finance the infrastructure and would be inclined not to meet those standards. Morris’ paper suggests that, from the transportation engineering perspective anyway, the new community movement aimed to create some degree of self-containment, and some degree of pedestrian promotion (primarily via safety), but not primarily to use alternative design and form to change traveler behavior.

<sup>44</sup> For example in 1973, *Savings and Loan News* (1973) features an article on planned unit developments (PUDs) as a possible response to environmental problems associated with development. Three projects are

early 1980s, the “urban village” concept arose, building upon the principles of compact fringe growth, urban infill, mixed uses, transportation choice, and affordable housing (Priest, 1982).

Congestion worries and development patterns had, by at least the mid-1980s, many authorities focusing attention on the concept of the jobs-housing balance as a possible solution (e.g., ABAG, 1985). Towards the end of the 1980s, a focus on “neo-traditional development” emerged, which grew into the “new urbanism” movement, largely reflecting the principles of the “urban village” concept (see, e.g., CNU, 2001). Today, these principles can largely be found within the rhetoric of the broader new urbanism “family,” including traditional neighborhood development, transit-oriented development, and more broadly “smart growth.” Within these urban planning and design “philosophies” resolving transportation ills (e.g., congestion, “auto dependence”) figures highly, as evidenced in a seemingly never-ending flow of relevant analyses, including more recent efforts to make direct links to other public policy concerns, such as obesity and public health.<sup>45</sup>

## IV.2 Scales of Effects and Means of Influence

Settlement patterns provide the basic spatial context within which people make their travel decisions. In metropolitan areas or regions, the built environment’s influences on travel behavior, in general, occur – and can be categorized and analyzed – at three different spatial scales (see Table IV-1):

- the *metropolitan* (or macro) scale, which I refer to as **urban structure**, such as overall scale (area), density, and “generic” development pattern (e.g., radial, concentric, poly-centric);
- the *intra-metropolitan* (or meso) scale, which I refer to as **urban form**, such as patterns of density within different sub-areas, the degree of jobs-housing balance, suburban versus center city, road network layout, etc.; and,
- the *local/neighborhood* (or micro) scale, which I refer to as **urban design**<sup>46</sup>, such as local street configurations, land use types and densities, amenities (e.g., sidewalk provision), etc.

Theoretically, the urban structure, form and design effects represent different scales of, essentially, the same general forces of influence. The built environment influences travel behavior by determining the total number of potential activities (i.e., employment, shopping, entertainment, etc.) available; the relative distribution of those activities and, thus, travel distances; and the relative travel costs implicit in traversing those distances by various modes.

---

highlighted: Greenwood Village (between Cleveland and Akron), 1000 acres originally zoned as one-acre homes and rezoned for a mix of 4,000 units townhomes, garden apartments, high rise, etc.; “The Village” (in San Diego), with “clustered” single family dwelling units (SFDUs) on 65 acres, planned for 8.3 units per acre; and Whispering Hills (in Greater St. Louis): again, with a clustered mix of SFDUs, apartments, townhouses, including community center, parks.

<sup>45</sup> For example, in September 2003, the American Journal of Public Health dedicated an entire issue (Volume 93, Issue 9) to research on the influence of the “built environment” on human activity levels and health.

<sup>46</sup> Note that urban designers may not fully agree with this terminology/categorization.

At the Metropolitan (macro) scale, the overall area of a city determines, for example, a theoretical maximum travel distance for intra-urban trips and the density of jobs, housing and services will thus determine average travel distances. A denser city will, all else equal, also reduce the operating costs of and increase the attractiveness of public transport, will increase the relative attractiveness of non-motorized transport and, lead to higher capital costs for infrastructure (due to land scarcity). As such, a higher (lower) density metropolitan area would tend to decrease (increase) the attractiveness of private motorized travel, and vice versa. Other urban structure-related phenomena, such as the degree of concentration of jobs in the center city (i.e., monocentricity), the population distribution relative to the city center (i.e., density gradients) and city-wide jobs-housing balance also provide broad macro-scale measures. Considering these structural indicators, theoretical generalizations are more difficult. In a highly monocentric city with a steep density gradient, the residents of the denser areas closer to downtown would more likely find jobs and other destinations nearby and therefore would be expected to make shorter trips, with a higher share of non-motorized travel. Finally, the total number and quality of activities in an metropolitan area – and that urban area’s location relative to other activity centers (and the quality of the connections to those other areas) – can also influence residents’ propensity to make trips outside of the city: for work, cultural, social, recreational, and other opportunities. In this sense, one can think of the metaphor of the “network of cities.”

**Table IV-1. The Built Environment and Travel: Scales of Analysis and Influence**

<b>Scale</b>	<b>Referred to As</b>	<b>Relevant Built Environment and Transportation Indicators</b>	<b>Built Environment Influences on Travel</b>
<u>Metropolitan</u> (macro)	Urban <i>Structure</i>	Overall City Size, population, gross density, “skeletal” forms (e.g, radial)	Total number of potential activities; maximum intra-city travel distances; relative modal attractiveness
<u>Intra-Metropolitan</u> (meso)	Urban <i>Form</i>	Dispersion, concentration, mixes, “coarse” grain, access networks	Relative attractiveness of different areas of the city; trip distances; “transit-oriented” development
<u>Micro Scale:</u> (neighborhood)	Urban <i>Design</i>	“Internal Texture”, local street configurations, “fine” grain, amenities (e.g., sidewalks), etc.	“internal” capture of trips, relative friction; “pedestrian-environment”

Moving from the macro scale to the meso scale, one can consider the metaphor of the “city of cities.” While no strictly defensible definition of the “meso scale” unit of analysis exists, I use the term here to refer to urban form measures that reflect the intra-metropolitan distribution of activities, such as jobs and residences, the relative mix of other land use types, and the relative location and type of new developments. The most basic meso-scale differentiation might be center city versus suburb. A relevant spatial unit of analysis in a large multi-jurisdictional metropolis may be the municipality or the

traffic analysis zone (TAZ) – the basic spatial unit of analysis in travel forecasting models. Overall, the primary relevant meso-scale characteristic relates to an area’s given location within the metropolis; this location affects its probability of being located near other activities and thereby influences likely trip distances and mode choice. Furthermore, particular development forms, for example, clustering of development around public transportation stations (i.e., transit-oriented development), would influence the attractiveness of this mode by increasing its ease of access to a number of activity opportunities.

Finally, while meso-scale effects refer to relative location, micro-scale effects refer to the local design characteristics within a given location. For example, suburban (i.e., meso-scale) locations may differ significantly in terms of activity opportunities within the immediate (micro-scale) vicinity. In the case of transit-oriented development (the general clustering or “corridorizing” of which represents a meso-scale phenomenon), micro-scale design considers the types of uses within a particular development and their layout. The meso-scale may represent a coarse degree of land use mixing within a given zone, but the micro-scale would consider, for example, the relative friction between those land uses (caused by, e.g., wide roads). Basic theory holds that, all else equal, street configurations and design can improve the relative utility of certain modes by directly influencing travel speeds and distances and/or the quality of the travel experience (e.g., a “safer” pedestrian environment). In addition, local level mixes of land uses can reduce travel distances.

In reality, the macro/meso or meso/micro lines are blurred. For example, no strict delineation can necessarily be found between a “neighborhood” and a metropolitan sub-region (discussed further below). Furthermore, it is not clear the degree to which urban *form* dictates a large share of urban *design*: for example, relative meso-level land use mixing may, in practice, require particular neighborhood design characteristics (e.g., accommodating certain density levels may force narrower street designs and/or certain building layouts and land use configurations). In some cases, meso-level characteristics might thoroughly overwhelm any potential micro-scale effects on travel behavior, which may be the case, for example, in a “neo-traditional” development on the exurban fringe. Furthermore, there is not even clear differentiation within a “scale.” For example, micro-scale might also be thought of as “site design” (e.g., Ocken, 1994), or a development (e.g., planned urban development or PUD), or a neighborhood. In this research, I propose that micro-level refers to the characteristics internal to a particular area (a “neighborhood”), and the characteristics that make that neighborhood similar to or different than other neighborhoods; defining the concept of neighborhood receives more attention in the following Chapter). In this regard, meso-level refers to a particular neighborhood’s context relative to the rest of the metropolitan area.

Finally individual traveler behavior may well be influenced by effects at all three scales.

#### *IV.2.1.1 Built Environment, Utility, and Travel Demand: Means of Influence*

In looking at the analyses and trying to understand potential effects, we need to keep in mind the need for a consistent theoretical framework. Crane (1996) attempted to explicitly pull the relevant analyses into a strict microeconomic behavioral framework

(which already had a long history in travel demand analyses; e.g., Ben-Akiva and Lerman, 1985), whereby travelers were assumed to maximize their utility subject to time and budget constraints and land uses influence trip-making through impacts on trip costs. In this framework, ambiguous effects can be expected, as lower trip costs (e.g., through shorter distances) may produce, for example, a higher trip rate, depending on the elasticity of trip demand with respect to cost (an empirical question which may depend upon trip type). At least one shortcoming of Crane's framework stems from being a trip-dependent utility measure, where, for example, the number of trips by each mode for each purpose figures directly into the utility measure.

A more theoretically attractive framework would focus on the activity-realization benefit of travel. In other words, the trips by a given mode do not feed directly into an individual's utility; instead, utility is derived by the activities that the trips facilitate (following from transport as a derived demand). *This is consistent with the accessibility-as-benefit sustainable mobility framework derived in the previous Chapter.* Maat et al (2005) offer an analytical approach along these lines. They suggest that most research on the influence of land use on travel behavior has taken a decidedly cost-based perspective; in other words, land uses influence the cost of travel and thus behavior (this is Crane's line of reasoning). Maat et al, however, note the need to include the benefit (utility) side of travel as well. In this sense, land uses influence net utility: i.e., activity realization (the positive utility) minus travel cost (including time) (the disutility). This perspective, extending beyond Crane's, shows that the ambiguity of land use influences on travel behavior may not only arise through the uncertain influence of trip costs (disutility) on travel, but also through influence on potential activity destinations (utility). For example, if land use changes reduce an individual's travel time, that individual might invest that time in increased activity time (e.g., spending more time shopping), the substitution of preferred destinations (with no net change in travel time) or the scheduling of additional non-home activities. The latter two cases would result in increased travel and are consistent with the idea of constant travel time budgets (e.g., Schafer, 2000).

Of course, and relating back to the previous Chapter's discussion of accessibility, an individual traveler's (or "activity participant's") own characteristics and situation (e.g., income, lifestyle, perception of available opportunities and ability to take advantage of such opportunities), as well as the type of activity being realized will also significantly influence trip behavior. Regarding the latter, Vilhelmson (1999) offers a useful categorization scheme for trips, based on the temporal and spatial flexibility of the related activities (see Table IV-2). According to this categorization, most work and school trips would fall into cell one – with a fixed time and location. At the other extreme comes those activities in cell four, with a flexible time and location; here we might find weekend leisure and social trips. In the intermediate cells two and three would be found, for example, grocery shopping trips (cell two) and particular recreational activities (such as a museum visit; cell 3).

#### *IV.2.1.2 Variation by Activity Purpose*

The Classification suggested in Table IV-2 enables a way to think about trip-making, the potential role of space in influencing constraints, and the timeframe of expected change.

For example, many, if not most people face limited flexibility – at least in the short- to medium-term in regards to work and school locations. Despite, then, ongoing calls for jobs-housing balance, non-discretionary trip-making will likely be limitedly affected by , at least micro-scale built environment influences. Clearly, exceptions to this exist, such as live-work space options for, e.g., artists or micro-entrepreneurs; temporary workers, who may make explicit location-based

**Table IV-2. Activity Classification Based on Time and Space Requirements**

Temporal Constraints	Spatial Constraints	
	<i>Fixed</i>	<i>Flexible</i>
<i>Fixed</i>	(1) Required activity; Specific place	(2) Required activity; optional place
<i>Flexible</i>	(3) Optional activity; specific place	(4) Optional activity; optional place

Source: Vilhelmson (1999).

The optional place activity types (cells two and four), seem thus more well-suited for potential targeting via built environment interventions. Even, here, however, important variations exist. Consider, for example, the case of shopping trips. A key determining factor in shopping trip is comparison versus convenience goods (Holton, 1958); to some degree this will be correlated with the expense of the product (or bundle of products) and the potential competition in pricing. Travel time will much more influence low-cost convenience shopping decisions (for example, the decision of where to go to purchase a quart of milk). The size of the expected purchase will also be influential, as people will not be willing to walk (even to the grocery store) if they expect to purchase heavy and/or bulky goods. Additional influencing factors relate to people’s perceptions of shopping opportunities available. One would expect this to be influenced by “cache” – shopping at an upscale mall or on Fifth Avenue (NY) (or Newbury Street, Boston), for example. This reflects the idea that shopping, in many cases, is as much a social activity as it is a utilitarian activity, epitomized, for example, by kids hanging out at the mall or, even, families and people wanting to be “seen” at the mall. This, in turn, is related to consumerism-defined identity, which is certainly an influencing factor in our increasingly consumer-driven world.<sup>47</sup> Handy and Clifton (2001) provide a more detailed review of relevant issues. Furthermore, Maat et al (2005) show, at least theoretically, that the decision to travel may be influenced by potential subsequent activities (spatial scale economies), such as, traveling to a particular shopping district, which is closely clustered to other shopping possibilities. In this case, trip-chaining possibilities become relevant.

All of this, of course, is also related to some fundamental doubts of transportation as purely a “derived demand.” In other words, some travel does occur for the pure sake of travel; or, at least, travel is not necessarily always viewed by travelers with as much disutility as analysts will traditionally assume.

<sup>47</sup> Vasconcellos (1997) talks about a related issue in the “making of middle class.”

### IV.3 Analytical Precedents

As noted in the introduction to this Chapter, analyses of the influence of the built environment on travel behavior have a long history. Reviews of early studies can be found in RERC (1974) and Hanson (1982). In 1992, prior to the “boom” in relevant research that arose from the growth in interest in the “new urbanism,” Handy (1992a) reviewed 49 relevant studies dating back to 1963. Many more recent reviews exist, including Handy (1996), Anderson et al. (1996), Crane (2000), Badoe and Miller (2000), Ewing and Cervero (2001), and TCRP (2003). The reviews vary in their approach to categorization. Handy (1992a, 1996) and Crane (2000) take a methodological-orientation to classification. Both authors essentially differentiate by analytical technique, including explicit or implicit consideration of the degree of aggregation of data utilized.<sup>48</sup> In their review, Badoe and Miller (2000) group the studies very broadly according to the basic mode choice decision modeled, while Ewing and Cervero (2001) categorize the studies according to the types of land use effects analyzed.<sup>49</sup> The TCRP (2003) review follows a “strategy”-orientation, assessing the evidence in three broad strategic intervention categories – density (of development), diversity (of land uses), and design (of site) – with both specific (e.g., metropolitan area level) and implied (e.g., site design) consideration of spatial effects.

Building on these precedents, I propose a spatial- and technique-oriented categorization of relevant analyses (see Table IV-3). The approach attempts to differentiate analyses based on: the spatial scales (as outlined above); whether the *travel* data used are aggregate (i.e., averages for zones or cities) or disaggregate (i.e., household or individual observations); and whether the analytical techniques are largely comparative (e.g., quasi-experimental) (often using primarily basic descriptive statistics techniques); based on multivariate regression (i.e., econometric); or based on what I have somewhat awkwardly

---

<sup>48</sup> Handy (1992a) broadly categorizes the approaches as: empirical, which essentially study existing relationships (e.g., through cross-sectional or time-series data); and experimental, studies which use assumed relationships (generally derived from empirical studies) to predict future outcomes given alternative inputs (e.g., changes in land uses). Under this classification scheme, traditional travel forecasting techniques would be considered experimental. Handy further differentiates empirical analyses according to the technique (e.g., cross-sectional) and type of data used (e.g., aggregate) and experimental analyses according to modeling approach (e.g., transportation model) and base for analysis (i.e., real or hypothetical city). Handy (1996) refines her earlier classification, essentially renaming experimental as hypothetical; and then instead categorizing empirical as aggregate analysis, with statistics analyzed at the, e.g., zonal level; disaggregate analysis, using household or individual level information; choice models, using techniques grounded in random utility theory; and activity-based analysis. Crane (2000) takes a similar methodology-based categorization approach, grouping studies as: hypothetical (e.g., simulations, including travel forecasting); descriptive studies, essentially comparing different development types (at the meso- or micro-scale); “ad hoc” multivariate analyses, which may include regression analyses; and demand models, which aim to embed multivariate analyses within an explicit behavioral theory. This last category can include discrete choice modeling approaches (e.g., multinomial logit), although as Handy (1996) points out, “a true choice model reflects a sound theory” (p. 159).

<sup>49</sup> Ewing and Cervero (2001) review: 14 studies comparing neighborhood (and activity center) designs; 35 studies testing specific land use variables; 10 studies including transport network variables; five studies testing urban design variables; and 11 studies testing composite indices.

termed “cost-based” econometric.<sup>50</sup> This latter category refers to, essentially, analytical techniques in the discrete choice tradition, but that explicitly include relative mode/trip cost variables. In other words, some analyses (e.g., Bento et al, 2004; Cervero and Kockelman, 1997) use discrete choice models but with no explicit incorporation of relative trip costs (which, in theory, should play an important role in relative utility of each mode).<sup>51</sup> This differentiation is important in that it reflects the increasing tendency to merge analyses of the built environment’s influence on travel behavior with the “discrete choice” tradition in travel behavior analysis; in particular the role of travel costs in the equation. Crane (1996) can, perhaps, be credited with the move towards more explicit, behaviorally-based analyses (with explicit need to understand the role of travel costs (e.g., distances, times).

Finally, the broader analytical categories, simulation or empirical,<sup>52</sup> aim to differentiate between those analyses which explicitly contain some projective modeling effort (“simulation”) and those which “simply” aim to explain observed behavior (“empirical”). Within the simulation category, “Real” refers to simulations based on actual empirical data; hypothetical refers to analyses based on “hypothetical” cities/data (not on hypothetical future conditions of an actual city). Within “simulation” one would find the typical travel forecasting efforts; here only a select few are included, namely those that explicitly looked at utilizing land use interventions as an explicit transportation strategy (e.g., LUTRAQ, 1996). Simulations can also include very basic projections based on regression models; some empirical analyses include some explicit simulations/projects.<sup>53</sup> It is helpful to recall that simulations generally depend on some empirical (observed) relationship. So, while, empirical methods aim to detect differences, simulations use known relationships (based on empirics) to estimate/predict effects.

In reality, the relevant studies cannot always be so simply categorized as macro, meso, or micro (in part due to the definitional difficulties mentioned above as well as due to the fact that many studies focus on more than one scale, either explicitly or implicitly). Furthermore, some analyses will combine both methodologies and data types. In addition, the measures used to represent the built environment tend to vary considerably across the studies.<sup>54</sup> Finally, the analyses often vary considerably in regards to the behavioral outcome analyzed, e.g.: trip frequency, trip time, trip distance, mode share, or some combination. Such variations complicate efforts to summarize and generalize results.

The following sections discuss a selection of results based on Table IV-3’s classification.

---

<sup>50</sup> Some will argue that the term econometric implies underlying theory, as opposed to regression techniques on their own. I find no unanimity on this issue in the literature. In strict rigor, econometric techniques should only be employed after the theoretical basis has been firmly established.

<sup>51</sup> Adams (1959) used LOS proxies; Cervero & Kockelman (1997) include Euclidean distance; Bento et al (2004) include average auto-use costs, no transit costs, but basic city-wide transit service levels.

<sup>52</sup> Many of the empirical analyses combine techniques (e.g., comparative descriptive statistics, with multivariate regression) and scales (micro/meso, macro/meso).

<sup>53</sup> Simulations can use either aggregate or disaggregate data. Many empirical analyses include simulations.

<sup>54</sup> In the table, some simplification and consolidation of measures were used. For example, regional and local accessibility (e.g., distance-/potential-based) were sometimes explicitly used in the studies (e.g., Handy, 1992b; Krizek, 2003c), while other studies do not necessarily use the actual term accessibility.

**Table IV-3. The Influence of the Built Environment on Transport: Example Approaches by Scale and Technique of Analysis**

Scale	Representative Measures of Built Environment	Simulation		Empirical						Examples of Analytical Purposes (i.e., to capture the influence of the built environment on:)
		Real	Hypothetical	Aggregate			Disaggregate			
				Comparative	Multivariate Regression	Cost-Based Regression	Comparative	Multivariate Regression	Cost-Based Regression	
Macro	UA(1,9,6,8), P(1,2,5,6), PD(4,5,44,45), EC(2), PC (9), CS(9,7); RD(9); JH (9), LUM(6); NS(3,7)	1,2,9,44,45	3	4	1,2,5,6,44,45	--	7	8,9		Auto ownership (5,9,44,45), mode (2,6,8,9,45), transport energy use (2,4), distances traveled (1,2,8,9), various travel indicators (3,7)
Meso	CBD(2,14,16,22,26,28),TOD(10,42), LUM(11,16), PD(27), NS(12,20,26), EC(14,16,27), EA (13,14,15), RA (17,18,19,20,22,23,24,29,46)	2,10,11,16,42	12	13	2,14,15,16	--	17,18,19	8,20,21,22,23,24,25	26,27,28,29,30,46	Various indicators (10,42), energy/GHG (2,11,12,16,19), distances traveled (8,13,14,15,16,18,21,22,24), mode (8,17,30,46), trip rate (2,17,18,20,21,22,26,27,28), trip tours/chains (23,24,29), auto ownership(16)
Micro	PD (2,14,15,25,27,29,30,38,40,41,43) EA(13), DUD(16,2,34), LA (17,20,22,23,24,25,27,37), NT (7,17,18,19,31,33,34,35,36,39), NS(15,16,20,26,27,28,29,30,32,37,38,41,46), LUM (20,25,26,28,29,30,37,38,40,43,46), PEF (10,25,27), TOD(42)	2,10,16,20,31,42	32	13,34	2,14,15,16,34	--	7,17,18,19,33,35,36	20,21,22,23,24,25,31,33,37,38,39	26,27,28,29,30,40,41,43,46	Energy use (2,16), trip rate (20,34,33,35,36,38,39,43), various travel indicators (32,42), distances traveled (13,21,22,24,33,39), duration (39), mode (31,33,34,35,37,40,41,46)

Letters refer to: UA: urban area; P: population; PD: population density; EC: employment centrality (macro)/concentration (meso/micro); PC: population centrality; CBD: distance to CBD; CS: city shape; RD: road density; JH: jobs-housing balance; LUM: land use mix; NS: road network structure (including, in some cases, presence of NMT facilities); TOD: transit-oriented development; DUD: dwelling unit density; EA: employment accessibility; RA: regional accessibility; LA: local accessibility; NT: neighborhood type; PEF: pedestrian environment factor or similar amenities.

Numbers refer to: 1. Cameron et al, 2003; 2. Cheslow and Neels, 1980; 3. Jamieson et al, 1967; 4. Newman and Kenworthy, 1989; 5. Ingram and Liu, 1998; 6. Adams, 1959; 7. Snellen et al, 2001; 8. Dieleman, et al, 2002; 9. Bento et al, 2004; 10. LUTRAQ (1996); 11. LABTUS (2005); 12. Edwards & Schofer, 1976; 13. Handy, 1993; 14. Miller & Ibrahim, 1998; 15. Holtzclaw et al, 2002; 16. IBI Group, 2000; 17. Handy, 1992b; 18. McCormack et al, 2001; 19. van Diepen & Voogd, 2001; 20. Meurs & Haijjer, 2001; 21. Hanson, 1982; 22. Røe, 1999. 23. Krizek, 2003a; 24. Krizek, 2003c; 25. Cervero & Kockelman, 1997; 26. Crane and Crepeau, 1998; 27. Greenwald & Boarnet, 2001; 28. Boarnet & Crane, 2001a,b; 29. Srinivasan, 2001; 30. Cervero, 2002; 31. Cervero & Radisch, 1996; 32. McNally and Ryan, 1993; 33. Handy & Clifton, 2001; 34. Cervero & Gorham, 1995; 35. McNally & Kulkarni, 1997; 36. Handy, 1996; 37. Greenwald, 2003; 38. Boarnet & Sarmiento, 1998; 39. Khattak & Rodriguez, 2005; 40. Zhang, 2004; 41. Rodriguez & Joo, 2004; 42. Swenson & Dock, 2003; 43. Zegras, 2004; 44. Beesley & Kain, 1964; 45. Kain and Beesley, 1965; 46. Rajamani et al, 2003.

### **IV.3.1 The Metropolitan (Macro) Scale: The Effects of Urban Structure**

As mentioned above, metropolitan scale analyses generally account for urban structural measures, such as overall metropolitan population and area, size of the central business district (CBD), and average population densities. Such analyses provide some scope for inter-city comparisons and can also lend some support for policy generalizations. Nearly all such analyses are comparative, utilizing correlations, multiple regression, or in at least one case, discrete choice models. Generally, cross-sectional travel behavioral data is used, either aggregate or disaggregate.

#### *IV.3.1.1 Empirical*

Adams (1959) provides an early example of using multiple regression analysis on travel survey data from 16 U.S. cities. He develops a model to predict city-wide transit mode share, basically finding that log-linear transformations of total commercial and industrial land area, population, an economic indicator, transit level of service, a land use distribution factor (a composite index of various land use concentrations relative to the CBD), and total urbanized land area to be reliable predictors. In the early 1960s, Levinson and Wynn (1963) reviewed several studies from the late 1950s and early 1960s in select US cities, examining relationships between city size, age, and density and automobile ownership (and use) and public transportation patronage; they find “the most significant effect of density” to be the “close correlation” with public transport use and suggest that city density is a valuable basic criterion for evaluating urban transportation needs. In the mid-1960s, Beesley and Kain (1964), using data from 45 US cities in 1960, developed a regression model to predict automobile ownership as function of median household income and gross city-wide population density; and Kain and Beesley (1965), using data from the same 45 US cities, derive reduced form equations to predict transit use based on income and density, finding the indirect effect of density influencing auto ownership and, thus, transit use to be larger than the direct effect of density influencing transit use.

In the 1970s came the well-known work of Pushkarev and Zupan (1977), which included inter-city comparisons to identify metropolitan area land use characteristics (e.g., size of the downtown and residential densities) that influence public transport demand (e.g., percent of workers using public transport for trips to work). Cheslow and Neels (1980), drawing from data on eight US metropolitan areas, conclude “the more compact or dense an urban area is, the less fuel used” (p. 764). At the end of the 1980s, Newman and Kenworthy (1989) offer one of the most oft-cited such studies – an international comparative analysis of urban areas, which, through simple bivariate correlations, they claim supports the argument that denser cities result in lower per capita gasoline consumption (Newman and Kenworthy did not control for other influencing factors such as income and fuel prices). In the 1990s, Schimek (1997) through multivariate regression models, explored several influencing factors on public transport ridership in US and Canadian cities, finding a modest influence of urban area population density and central city employment relative to other factors, including public transport fares and service levels and household auto ownership. Ingram and Liu (1997) looked also at an

international spectrum of cities, finding long run (cross sectional) elasticities for the urban motor vehicle fleet of -0.4 for population density – one-half of the estimated income effect and less than one-half of the effect due to population size. Drawing from an updated and expanded version of the original Newman and Kenworthy data for 1990 (Kenworthy et al., 1999), Lyons et al. (2003) propose a generalized urban transport emissions model based on the relatively strong positive empirical relationship between total VKT and urban area size. Their results lead them to the broad policy recommendation of containing urban area physical expansion to reduce emissions, a result which naturally leads to the need for densification (the “compact city”) in the face of ongoing population growth.

Also drawing from the Newman and Kenworthy data, but this time building from data for four different time slices (1960, 1970, 1980, 1990), Cameron et al (2003) develop a model aiming to predict city-wide private motorized mobility levels based on macro-level data. Using dimensional analysis, they determine that private motorized mobility can be effectively predicted based on urban form and a traffic saturation factor (which explain between 85% and 92% of the variance). They find that the predictive function remains constant in time and does a fairly good job of predicting private motorized mobility levels in other cities (even less developed Asian cities, when motorized two-wheelers are accounted for). Their findings lead them to generalize that urbanized land area and population determine aggregate vehicle distances traveled.

Recently, Bento et al (2004) use the 1990 Nationwide Personal Transportation Survey (NPTS) to explore household travel behavior in the urbanized portion of 114 U.S. Metropolitan Statistical Areas (MSAs).<sup>55</sup> This study differs from the previous studies in that it uses disaggregate individual travel data, together with macro-level land use measures,<sup>56</sup> together in a discrete choice modeling framework. For the urban areas, they construct various measures of urban structure and public transport supply, including city shape (how close to “circular” the city is), city size (urbanized area), road network density, population centrality<sup>57</sup>, jobs-housing balance (deriving a zip-code based Gini-coefficient), and normalized bus and rail route miles supplied. They use this data to estimate multinomial logit (MNL) choice models for commute trips and vehicle choice model (0,1,2,3 vehicles); and an ordinal least squares model (using the selectivity correction approach to link the vehicle choice MNL) to predict vehicle distances traveled. Their findings indicate some influence of urban structure measures: increased road density decreases rail choice; increased sprawl (see note 57) decreasing bus use but increasing rail use; and jobs-housing balance increasing non-motorized mode choice. For the vehicle choice models, they find increased sprawl to increase vehicle ownership trends, but confounding effects of density and land area. Finally, in the OLS regression, they find road density to increase vehicle use for 1 vehicle households and more circular

---

<sup>55</sup> Of the more than 22,000 households in the NPTS, 9,719 lived in the 114 urbanized areas for which land use and transport measures were available and 6,470 households lived in the 26 cities with some form of rail transit available.

<sup>56</sup> Some of these measures are derived at a meso-level; for example they derive a zip code-based Gini coefficient to represent jobs-housing balance.

<sup>57</sup> Developed as a Gini-coefficient, ranking census tracts by distance from CBD; with the interpretation intended by the authors to be: more uniform distribution of population meaning “more sprawl.”

city to decrease auto use for 1 vehicle households. Overall, the detected macro-level urban structure effects on mode and vehicle choice and use are mild, at best – most of the structure variables are insignificant (furthermore, the OLS equations have very low explanatory power; the relevant statistics for the MNLs are not reported).

#### *IV.3.1.2 Simulation*

A number of macro-level simulation (experimental) analyses exist, beginning at least in the 1960s and the advent of large-scale computer models. I consider these macro-level analyses because their basic concern is with general patterns of development (e.g. linear, cartwheel, centric city, spread city). For the most part, these are highly experimental studies, modeling “hypothetical” cities. Jamieson et al (1967), for example, specify six city designs (two cartwheel and four linear) and, utilizing a trip distribution and assignment model (assuming fixed trip generation and private/public transport mode share), they estimate the implied highway investment costs. Their analysis suggests a linear city model has the lowest average trip time (for peak period, auto work trips). Hemmens (1967) uses linear programming to assess the effectiveness of alternative city structures (e.g. “centric,” “ring”), under various transportation network alternatives (e.g., radial, ring). The results lead him to conclude that land use patterns perform relatively independently of the transport systems, leading him to suggest the “most efficient” land use structure can be “picked.” Neither of these two analyses are behavioral, per se; they are aimed at providing guidelines for development patterns. Most future studies using city-wide simulation techniques take a more detailed focus and are discussed under meso-scale analyses; although as mentioned, this is a somewhat arbitrary separation.

Several empirical analyses include some form of simulation from their regression results. Kain and Beesley (1965), for example, make projections for Leeds (UK) based on their models fitted to US city data, showing the sensitivity of future transit use estimates to urban structure measures (due to influence on auto ownership and transit use). Cheslow and Neels (1980) estimate that making a metropolitan area “more compact” could decrease auto trip distance by 43% and transportation fuel use by 35%.<sup>58</sup> Despite the modest measured effects of urban structure measures (not to mention very low explanatory power of the OLS regression), Bento et al (2004) use their models in a simulation analysis to suggest that the differences between cities (e.g., Atlanta versus Boston) impact the amount of household automobile travel (VKT) by as much as 25%.

#### *IV.3.1.3 Comments*

These various macro-level studies differ in many ways, including the extent to which they: control for influencing variables (e.g., travel times and costs by different modes); adjust for potential correlation among influencing variables (i.e., multi-collinearity) and/or simultaneity in effects (i.e., do people choose residential locations and then auto ownership levels or vice versa); and, attempt to distinguish between links in causal chains (e.g., effects on car ownership levels and subsequent effects on vehicle use). While they may allow for some broad generalizations about likely effects of urban size and density

---

<sup>58</sup> They use the example of giving a city the size of Youngstown (Ohio), of approximately 130 square miles, the CBD employment equivalent of Washington, DC (with 12% of the regional employment in the CBD) (values from 1970 Census; Cheslow & Neels, 1980; pp. 73 & 77).

and some influence on motor vehicle ownership and use, they offer few practical guidelines or direct policy-relevance. For example, Pickrell (1999), drawing largely from macro-level analyses, claims that the evidence shows that little impact is detected below the threshold density of 4,000 persons per sq. mile, leading him to a much less than optimistic prognosis regarding a realistic role for density in influencing travel behavior. What lessons can be drawn from such a number, however? In many places (particularly outside the U.S.) densities already exceed that level, while in many others such a level will likely never be achieved. The ultimate influences are much more nuanced and, as Ingram and Liu (1998) point out, analyses must take into account a “city’s historical endowment of buildings, street layout, block sizes, and related physical infrastructure” (p. 22). Macro-level analysis may support some general calls for the “compact city” (e.g., Cameron et al, 2003) but more detailed, city-specific, guidelines require meso- and micro-level analyses.

#### **IV.3.2 Intra-metropolitan (Meso-scale) Scale: The Effects of Urban Form**

Intra-metropolitan analyses move more closely towards direct policy relevance for managing urban form by accounting for, e.g., the relative separation/location of different activities and other rough measures of urban form, such as densities along certain corridors and variation of densities within a city. Early examples include Carroll (1952), who looked at the jobs-housing balance and implications for travel demand within several US cities and Marble (1959), who uses (surprisingly detailed) household travel diary data from Cedar Rapids (Iowa), finding no influence of relative location on trip rates (for shopping trips), but a measurable, albeit modest, effect of residential location (measured by distance to various shopping centers and nearest transit) on total miles traveled. Levinson and Wynn (1963) also report results from rough meso-scale analyses, such as within-city variation in car ownership based on dwelling-unit type, the spatial relationship between city age, density, car ownership and transit ridership (in Chicago); and within city relationship between density and transit mode share (Chicago, Pittsburgh).

##### *IV.3.2.1 Empirical*

Most of the meso-level empirical analyses actually also look at both meso- and micro-level effects. Remember, by meso-level we mean measures of relative location within the broader metropolitan area, such as distance to CBD or traditional location-based accessibility measures (see Chapter III) such as gravity-based functions. Examples using aggregate data include comparative approaches, like Handy (1993) who finds a negative correlation between regional accessibility (a gravity function of retail employment) and distances traveled for shopping trips. Cheslow and Neely (1980) find nearness to the CBD to be a strong influencing factor in auto use (VDT) by effecting total trip length (in US cities); a finding corroborated for Toronto (Canada) by Miller and Ibrahim (1998) (and IBI Group, 2000), who find distance from CBD to be the most important variable explaining VDT per worker. Miller and Ibrahim (1998) also find some support for the poly-nucleated urban form, as distance to nearest high density employment center is also positively correlated with VDT.

Using disaggregate data, most studies also seem to find an important meso-level role. A study of Dutch residential areas found relative location (i.e., “inner city” or “outer city”) to predominate in determining total household transportation energy use (although, most other potentially influencing factors, i.e., income, are not apparently controlled for) (van Diepen and Voogd, 2001). Similar effects of distance to CBD increasing travel length have been reported for Oslo (Røe, 1999), while Hanson (1982) reports of more modest effects of “relative location” on average travel distances for Uppsala.<sup>59</sup> For San Diego, Crane and Crepeau (1998) find increasing distance from the CBD to be positively related to household car trip frequency.<sup>60</sup> The role of relative location (measured by gravity function-type accessibility measures) on travel distance is confirmed by Cervero and Kockelman (1997) and Krizek (2003c) and on (auto) travel time by Srinivasan (2001). Krizek (2003c) finds no influence of regional accessibility on the number of tours (i.e., trips with potential chaining) nor on the number of chains in a tour, while Srinivasan (2001) does find an apparent influence of auto accessibility on trip chaining propensity (and travel time).

#### *IV.3.2.2 Simulations*

Continuing advances in computational power and the persistence of the energy crises of the 1970s and early 1980s spurred a considerable amount of “hypothetical” simulations, many focused on models of “prototype” cities, showing how altering “spatial structure” (e.g., controlling urban expansion, channelling urban development along transport corridors) could reduce transport energy consumption (e.g., Edwards and Schofer, 1976). These efforts, in most cases, utilized similar techniques to the traditional travel forecasting models (or Lowry-based integrated models), but with the goal of identifying generic, energy efficient, urban forms. The typical result was the heavily CBD-focused city, or the “polynucleated” form (see Weisel and Schofer, 1980; Figure IV-1 shows examples of the different urban forms analyzed by two different researchers in the 1970s).<sup>61</sup>

Such hypothetical city form models may provide some indicative guidance, but most guidance for cities comes from traditional travel forecasting models, which also fall within the meso-scale category of analysis. Despite non-trivial variations, and several advanced research prototypes, these models essentially still function, in practical applications, within the well-known “four-step” process that (sequentially) models: 1. Trip generation; 2. Trip distribution; 3. Mode choice; and 4. Trip assignment. In spatial terms, these models work with the traffic analysis zone (TAZ) as the basic unit of spatial analysis – in other words, land uses (e.g., square meters of commercial space) are characterized at the level of the TAZ and travel information, although collected at the

---

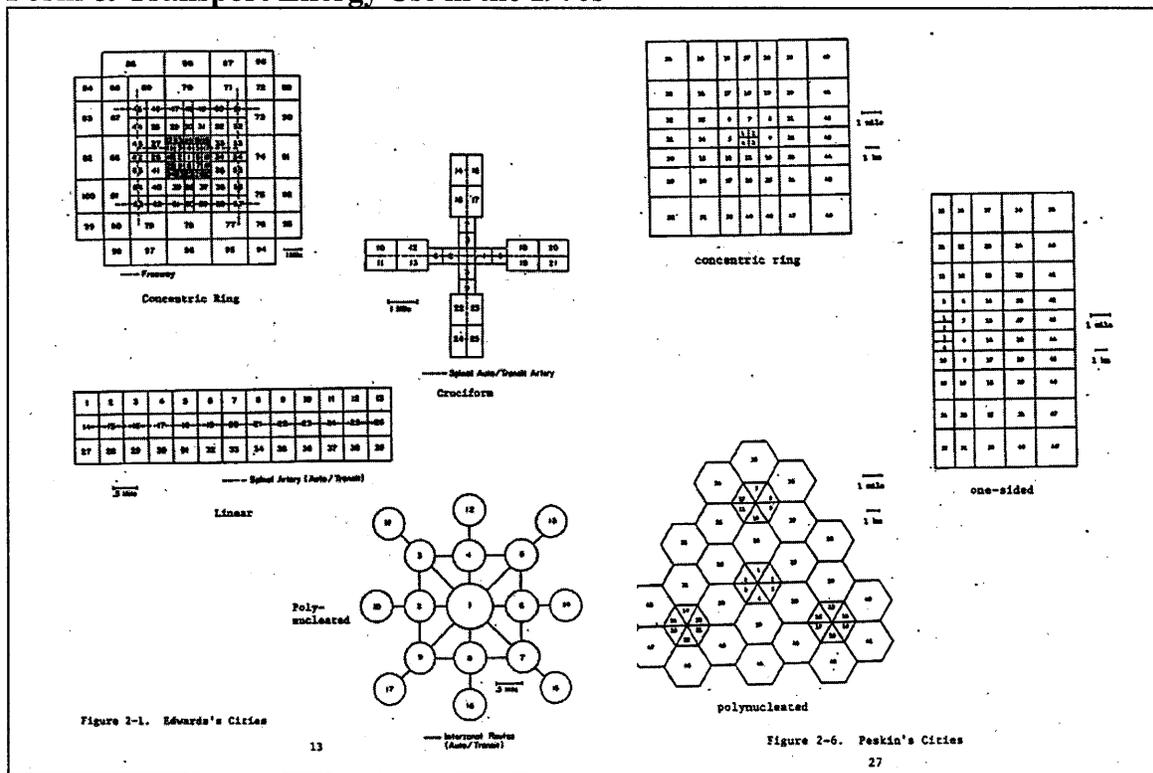
<sup>59</sup> Hanson uses a representative variable (establishments within 4 km from home) as a proxy for a number of variables loading strongly on a principal component (“far from home”); the proxy variable is negatively correlated with CBD distance (based on the loadings reported in the PCA results), so that the negative coefficient on that variable means a positive coefficient for CBD distance on average travel distances.

<sup>60</sup> Although the authors found auto trip frequency to be negatively affected by the square of CBD distance, indicating that at a certain distance from the CBD, perhaps sub-center proximity could decrease auto frequency.

<sup>61</sup> Note the inherent modernistic tendency of these efforts: the idea of creating an ‘ideal’ city from a *tábula rasa*.

individual/household level, is aggregated to the TAZ for the purposes of predicting travel flows between TAZs. In these models, land use normally serves as an input: the spatial distribution of land uses (activities) generally determines where trip production and attraction (i.e., the Trip generation stage) takes place. This relates back to the “predictive” focus mentioned earlier (Section IV.1): future land uses are determined either via “expert” judgment (e.g., trend-delphi techniques) or with a land use model (which in many cases operate in an integrated fashion with the travel model, whereby transportation performance in one time period influences land development patterns in subsequent time periods). Based on these predicted future land uses, transportation outcomes are forecast; these forecasts, in turn, are used to evaluate various potential transportation system interventions (e.g., investments, policies).

**Figure IV-1. Hypothetical Urban Forms Tested in Simulation Models of Urban Form & Transport Energy Use in the 1970s**



Source: Weisel and Schofer, 1980, pp. 13, 27.

Despite their historic “predict” and “provide” focus, traditional forecasting models have also been deployed, in more recent years, with the aim of assessing the possible role of urban form in influencing travel demand. In the United States, the pioneering effort was the LUTRAQ project, in the Portland (Oregon) metropolitan area.<sup>62</sup> LUTRAQ utilized integrated land use and travel demand models to assess the possibilities for using

<sup>62</sup> The LUTRAQ project director says that, to his knowledge, this was the first time in the United States that a land use alternative had been included in a transportation major investment study (MIS) (Bartholomew, undated).

alternative urban forms as a possible alternative to developing a new highway. Both meso- and micro-scale (see next Section) effects were modeled and, as mentioned earlier, these differences are somewhat artificial in language and certainly not entirely differentiable in practice. In any case, the LUTRAQ project examined an urban growth pattern that reinforced the planned public transport system, with no major changes in net metro-wide densities, but rather with higher densities shifted towards public transport (LUTRAQ, 1996). The effects on vehicle ownership and mode choice<sup>63</sup> were modeled and the land use alternative was estimated to have important effects on household auto ownership and use, mode share, travel times, energy consumption, among other impacts (LUTRAQ, 1996).<sup>64</sup> Other studies have followed somewhat in the LUTRAQ tradition in the U.S. (in terms of modeling land use options as a travel improvement strategy), including in Sacramento, California (e.g., Johnston et al, 2001), Atlanta, Georgia (Walters et al, 2000), and Minneapolis, Minnesota (Swenson and Dock, 2003).

#### *IV.3.2.3 Comments*

Overall, meso-level built environment measures seem to exhibit no effect on total trip rate (with evidence dating from studies of 1950s onwards; e.g., Marble, 1959, Hanson, 1982). While the empirical work cited above varies in how meso-level effects are captured (e.g., distance to CBD, etc.), the evidence suggests influence on distances traveled and mode choice.<sup>65</sup> The very limited evidence regarding trip chaining behavior is ambiguous, although it generally seems to confirm the fairly stable trip rate. Drawing from a range of analyses, Cervero and Ewing (2001) derive “typical” elasticities of vehicle trips and vehicle miles traveled (VMT) with respect to “regional accessibility.” They estimate no influence on vehicle trips,<sup>66</sup> but a -0.2 elasticity for VMT, meaning that a 1% increase in regional accessibility would produce a 0.2% reduction in VMT.<sup>67</sup> While not directly comparable, the IBI Group (2000) also finds that relative location (inner area, inner suburb, outer suburb) plays more of a role in determining household transportation energy use (GHG emission) than neighborhood type.

The early, hypothetical-city simulation models offered suggestions of “idealized” urban forms under the specific goal of reduced transportation energy consumption. In more recent years, forecasting models have been applied to real cities in order to gauge the possibility of using land use strategies for influencing travel demand. In at least one case (LUTRAQ), the results have apparently contributed to changing transportation investment plans (Bartholomew, undated). From such simulation exercises, it is not always possible to gauge which effects come from meso-scale effects and which from

---

<sup>63</sup> The model uses a “pre-mode” choice, whereby non-motorized trips are first estimated and taken out of the remaining model stages.

<sup>64</sup> They report an accessibility measure, percentage of population within 30 minutes of a certain number of jobs, persons, shopping as a performance indicator.

<sup>65</sup> Note, however, that Crane and Crepeau (1998) do not actually specify a mode choice model; they specify and estimate a trip frequency by mode (auto) model (problems with this approach are discussed below). In light of the evidence of non-varying total trip rate, the decline in auto trips associated with locations closer to the CBD *implies* trip substitution by not-auto modes.

<sup>66</sup> In an apparently updated version of the same elasticities (Criterion, 2002), a vehicle trip elasticity is also reported (-0.036).

<sup>67</sup> A gravity model-derived accessibility index is used.

micro-scale (or, which came from other proposed measures such as parking pricing); generally, however, forecasting models are not entirely well-suited to capture the micro-scale effects (discussed further below). More rudimentary simulation exercises (i.e., primarily utilizing regression equations for forecasting) suggest important effects: Cheslow and Neels (1980) for example, estimate that moving a neighborhood one quarter of the average distance to the CBD would reduce *auto* trip rate by 9%, distance by 19% and fuel use by 28%; IBI Group (2000) estimates that moving a neighborhood 30 kms from the CBD to 10 kms from the CBD, would reduce household transport GHG emissions by 20-40% (the range reflects differences in the “type of neighborhood,” i.e., micro-scale).

### **IV.3.3 The Neighborhood (Micro) Scale: The Influence of Urban Design**

In the mid-1950s, Reeder (1956), in a study of factors influencing journey to work travel mode, time and cost, included a census tract-based measure of residential classification, dwelling area rating (3 categories of dwelling areas were assigned somewhat subjectively to census tracts<sup>68</sup>), finding – on the basis of chi-square tests – no significant difference between dwelling area type and travel mode, time or cost. This effort may well have marked the first implicit attempt at measuring *micro*-scale influences on travel behavior in the U.S. Over the years, increased analytical sophistication (e.g., the adoption of multivariate regression techniques), better and more disaggregate land use and travel behavior data, and the ongoing improvements in computing power and software (e.g., GIS programs) – together with the apparent never-ending interest the potential of, for example, the “new urbanism” to actually influences travel behavior – have all contributed to tremendous growth in the number of relevant analyses.

#### *IV.3.3.1 Empirical*

In one of the first studies to explicitly recognize and attempt to quantify “neighborhood scale” (p. 77) effects, Cheslow and Neels (1980) estimate that a tripling of neighborhood densities (an admittedly crude measure of neighborhood design) would reduce the auto trip rate by 21%, auto trip distance by 5% and fuel use by 24%. Other empirical explorations using aggregate data find important effects. Handy (1993) finds a negative correlation between local accessibility – measured for a given TAZ<sup>69</sup> – and shopping distances, with no effect on shop trip rates. Although Miller and Ibrahim (1998) find no significant effect of TAZ-measured population density on home-based work trip VKT per worker for Toronto<sup>70</sup>, the IBI Group (2000) finds a significant effect of TAZ-level built environment measures on auto ownership and auto and public transport use (see Table IV-4). Holtzclaw et al (2002) use aggregate data from three U.S. cities to claim an apparent universal influence of residential density (measured by households per acre) on vehicle ownership and use. Cervero and Gorham (1995), comparing “auto” versus “transit” neighborhoods the San Francisco and Los Angeles metropolitan areas find a

---

<sup>68</sup> The survey interviewers and eight university students ranked the 41 tracts according to a categorization that, apparently reflected concepts such as “working men’s homes, ‘two-flat area’, single-family dwellings.”

<sup>69</sup> A gravity-formulated measure, using off-peak auto travel to nearest three zones and own-zone retail, service and other employment.

<sup>70</sup> Miller and Ibrahim (1998) do not control for socio-demographics or income in their analysis.

neighborhood influence on auto and NMT share mode shares (and trip rates) and also found evidence suggesting that “transit-oriented” neighborhoods show a higher potential to increase transit use through further land use changes (i.e., increased densities). Somewhat importantly, however, they also found some evidence that neighborhood effects may be overwhelmed by meso-/macro-effects, at least in Los Angeles. All these studies use aggregate travel data.

**Table IV-4. Micro-Level Built Environment (and Socio-Demographic Control) Variables Influencing Auto Ownership and Auto and Transit Use in Toronto**

Variable Category	Variables included in Each Model		
	Auto Ownership	Auto VKT	Public Transport PKT
<i>Socio-Economic/Demographic</i>	Adults per HH, HH income	Persons per HH, Avg. HH income, Avg. autos per HH	Predicted Avg. autos per HH
<i>Transportation Service Levels</i>	Local transit vehicle service hours		Local transit vehicle service hours
<i>Local Density</i>	# Stores w/in 1 km, Housing Unit Density		Jobs w/in 1 km, Stores w/in 1 km, Housing Unit Density
<i>Local Diversity</i>	Housing Type Mix, Avg. Unit Size	Land Use Mix w/in 1 km	
<i>Local Design</i>	Curvilinear Road Network, Bike Routes/Total Road Length	Road Type (grid), Intersections/Road-km, Wide Arterials/Total Road Length	Bike Routes in Neighborhood

Source: IBI Group, 2000.

Also comparing community types, but in this case using disaggregate data, Handy (1993) finds inconclusive effects of local accessibility on total non-work travel, as some degree of additional trip-making seemed possible. Looking at the Dutch case, van Diepen and Voogd (2001) find an “inappreciable” effect of neighborhood design on household transport energy use.<sup>71</sup> Handy and Clifton (2001), looking at shopping travel behavior among residents in Austin (Texas) (they use quantitative survey data and qualitative information from focus-groups), find evidence of no net effects on total travel distances, since short (walk) trips on some occasions tend to be complemented by more distant auto-based shopping trips. Note, however, that they do not look at other trip purposes and thus cannot capture possible effects on total travel. McNally and Kulkarni (1997) compare stylized neighborhood types (conventional suburban, traditional, and a hybrid of the two) in Orange County (Southern California)<sup>72</sup> and find no statistically significant difference among the neighborhoods in terms of mode choice or trip rate. In the Dutch setting, Meurs and Haaijer (2001) find, after controlling for relative location and

<sup>71</sup> Only two neighborhood “types” are compared after controlling for meso-scale effects: “traditional” and “sustainable” with the latter “characterized by a building plan that specifically aims at a reduction of undesirable and harmful environmental effects during utilization” (p. 67). Based on the few physical descriptors provided, it is not clear how these neighborhoods differ.

<sup>72</sup> 20 total neighborhoods compared; survey of more than 500 households.

socioeconomics, that neighborhood characteristics, primarily local shopping availability, increases bike and walk trips, but also increases all shopping and social/recreation trips, which seems to support the Handy (1993) and Handy and Clifton (2001) conclusions for US cities. One can actually infer the same general conclusion from the work of Cervero and Kockelman (1997) who, looking at the San Francisco Bay Area, find local built environment measures (including street network characteristics, building type, land use mix, and block type<sup>73</sup>) to exhibit significant effects on non-work VKT, but to exert no measurable influence on total household VKT – in other words, the micro-scale urban design might influence non-work travel vehicle use, but seems to have no net discernible effect on total VMT. Boarnet and Sarmiento (1998) find little measurable effect of micro-scale measures on auto trip generation rates in Southern California. The VKT versus vehicle trip distinction has non-trivial relevance for air quality, due to the fact that emissions rates are higher for vehicles during operations immediately after a “cold start.”

These somewhat doubtful results on the net role of micro-level land uses on travel behavior can be contrasted with other studies on disaggregate data, that show more room for sanguinity. McCormack et al (2001) compare neighborhoods in Seattle and find evidence of lower travel distances in mixed use neighborhoods (and slower speeds, implying a constant time budget), even after controlling for socio-economics. Cervero and Radisch (1996) find neighborhood type to be a strong predictor of mode choice for non-work trips, suggesting an important (intuitively appealing) influence on shopping, errand and other trips. In a more recent study, Krizek (2003c) finds local-scale design (housing unit density, land use mix, block size) to have a negative influence on both vehicle and person miles traveled, despite an increased average number of tours (fewer trips per tour; i.e., less trip-chaining in neighborhoods with high local accessibility).

**Table IV-5. “Typical” Elasticities of Travel with Respect to Urban Form and Design**

Urban Form & Dimension	Vehicle Trips	Vehicle Miles Traveled
Local Density	-0.05	-0.05
Local Diversity (Mix of Land Uses)	-0.03	-0.05
Local Design	-0.05	-0.03

Source: Ewing and Cervero, 2001.

As can be gleaned from this somewhat selective review of results, the studies cannot be simply generalized. Nonetheless, in their review of some 60-odd studies dating back to the late 1980s, Ewing and Cervero (2001) propose “typical” elasticities of vehicle distances traveled and vehicle trips with respect to micro-level urban design variables (see Table IV-5), which they suggest could be used in the absence of place-specific land use-travel studies. These partial elasticities can be interpreted additively, so that, combined, density, diversity and design (the “three D’s of local land uses) have an elasticity of 0.13 on distances traveled, meaning that every 1% increase in the combined 3Ds would produce a 0.13% percent decrease in vehicle distances traveled.<sup>74</sup> While these

<sup>73</sup> Somewhat confoundingly, they find a negative influence of the share of 4-way intersections on VKT, but a positive influence of share of square blocks.

<sup>74</sup> These elasticities have been incorporated into a sketch planning tool developed for the U.S. EPA (Smart Growth Index 2.0), which provides a hypothetical example of how the various land use dimensions can be translated to assess practical planning situations. For an approximately 390 hectare site, an “alternative”

elasticities apparently account for some second order effects, such as the impact of density auto ownership and, thus, auto use; other interactions, such as the impacts higher densities on transit levels of service, are not apparently accounted for (TCRP, 2003).

#### *IV.3.3.2 A Move Towards More Explicit Behavioral (Cost-Based) Modeling*

Some authors (e.g., Crane, 1996; Badoe and Miller, 2000) have suggested that part of the difficulty in fully generalizing the broad-ranging results from the relevant empirical studies comes from a failure to explicitly situate the analyses within a coherent behavioral framework (theory). Crane (1996) makes an important push in this direction, aiming to show, in a microeconomic framework, that the expected influence of the built environment on travel behavior is ultimately ambiguous, as it depends on the effects on prices, costs and quality (of travel). As such, the influences should be analyzed within a framework that can reflect influences on relative travel attractiveness. Somewhat logically, this leads directly to the comparative utility approaches (in the column labeled “Cost-Based Regression” in Table IV-3). Several researchers seemed to be moving in this direction around this time (e.g., Cervero and Radisch, 1996; Cervero and Kockelman, 1997<sup>75</sup>), but Crane and Crepeau (1998) are apparently the first who attempt to operationalize the Crane (1996) framework. This work would be followed by similar efforts in the “Crane School,” including Greenwald and Boarnet (2001) and Boarnet and Crane (2001). While signifying an important advance, the “Crane School” has some problems, most notably:

- the Cobb-Douglas preference specification (essentially necessary to “solve” the constrained maximization problem they pose) yields demand functions of a form whereby demand for the number of trips by a particular mode depends only on that mode’s price and also implies that individuals will allocate a fixed portion of their time to each activity, likely a limited representation of actual consumer behavior;
- unclear (weak) justification of the modeling technique (e.g., ordered probit, although the count-based nature of the trips most likely should be estimated as Poisson or negative binomial<sup>76</sup>) and subsequent interpretation of results;
- unclear derivation of user costs (i.e., level of service data for the relevant modes) and apparent selection of observations based on value of the dependent variable (i.e., the choice of trip or not)

In short, the “Crane School” makes an important push, but seems to suffer from some important shortcomings. A major doubt relates to why most of their efforts focused on

---

design which includes a doubling of population density (from 2.6 to 5 persons per hectare), a 25% increase in employment density (from 5 to 6.4 jobs per hectare), and changes to pedestrian facilities and street configuration (weighted components of the design dimension) would produce a 4% reduction in home-based private vehicle travel per capita per day (Criterion Planners/Engineers, 2002). They do provide additional details on, for example, the meaning of the various sub-components of the “Design” dimension and how they are weighted.

<sup>75</sup> In both of these papers, discrete choice models are used, but this is more to be consistent with the choice decision (discrete dependent variable), than with explicit cost inclusion, per se; although Cervero and Kockelman (1997) do include trip distance.

<sup>76</sup> Although the distributional assumptions of the relevant variables should ultimately dictate the modeling technique employed.

trip generation by a particular mode, instead of explicit mode choice for a given trip (which would more transparently build on comparative utility). In other words, nearly all analyses show fairly stable trip generation rates, irrespective of the built environment; as such, the key rests on mode choice for trips, which requires then explicit, *relative* costs (utilities) for different modes.<sup>77</sup> Efforts in this exact direction – more specifically, in the fully specified multinomial logit (random utility theory) tradition – would soon follow, including by Srinivasan (2000, 2001), Zhang (2002, 2004), Cervero (2002), Rajamani et al (2003), and Rodriguez and Joo (2004). All of these authors find *some* influence of the built environment – micro, meso, or both – although the authors differ still in model specification, both in terms of how the relevant modal attributes are included and/or whether critical control variables are included, most particularly household or traveler income (e.g., neither Cervero (2002) nor Rodriguez and Joo (2004) include income).

In general, the evidence of a built environment effect from these studies appears modest, although in most cases they are independent of the specific potential influence on travel times and costs. For Boston, for example, Zhang (2004) finds: population density at the zone of trip origin and destination to increase the likelihood of walk, bike or public transport for work trips; the share of cul-de-sacs to positively increase the drive alone likelihood (he finds that the land use variables do influence the transit cost coefficient, suggesting some substitutability between land use attributes and transit cost in explaining mode choice).<sup>78</sup> For the Hong Kong case, Zhang finds job density at trip origin (perhaps a jobs-housing balance proxy) to increase the likelihood of taking public transport for work trips and population density at the trip origin to increase the probability of taking public transport for non-work trips. Rodriguez and Joo (2004) find topographical factors and sidewalk amenities to be significantly associated with non-motorized travel, but also find density to be negatively associated with the probability of taking the bus (they interpret this as meaning that density actually increases the attractiveness of the non-motorized modes relative to bus).<sup>79</sup> Rajamani et al (2003) find the only significant built environment factors to be land use diversity and cul-de-sac street share on walk mode choice. Regional accessibility is not quite significant (which is not surprising, since this effect in their model should already be captured in the trip characteristics [e.g., time/cost]); park area is nearly significant for walking. For walk mode choice, land use mix exerts more influence (10 times) than income (based on aggregate level elasticities), but just one-third the affect of vehicle availability (vehicles per adult).

In theory, random utility models in the logit tradition offer an attractive way to capture the relevant influences of the built environment on travel in a behaviorally rigorous way. Their applications (as evidenced above) suggest some improvements, but doubts remain. In any case, the models themselves, while theoretically attractive, face practical challenges in implementation – namely, accurately specifying the attributes of the

---

<sup>77</sup> Obviously, if trip rates are fixed, then predicting trip rate by one mode instead of another is akin to predicting mode choice; however, the key in this estimation is including the costs/prices of all relevant modes in the *potential* choice set.

<sup>78</sup> Of the various applications of MNL models mentioned in this paragraph, Zhang most closely adheres to the most rigorous specification, including mode cost interacted with income, which helps directly reflect the income sensitivity of cost.

<sup>79</sup> Density in their model is measured at the block group

alternatives. A well-specified logit model needs to include the relevant variables, including levels of service of the relevant alternatives.<sup>80</sup> These are not always available and often then derived from travel models. In this case, problems could come from the inaccuracies of those models and/or the fact that the models may not provide information for relevant periods of travel (e.g., off-peak periods) and generally will not have relevant information for intra-zonal trips (making it difficult, for example, to estimate non-motorized choice). This is all critical when thinking about using such models for estimating welfare-based accessibility. In theory the discrete choice framework is attractive, in practice a number of assumptions and data shortcomings must be overcome to be able to actually estimate a model.

#### *IV.3.3.3 Simulations*

The move towards discrete choice models offers, possibly, a direct “conversational” link between the empirical (e.g., cross-sectional, comparative static) analyses discussed above and traditional travel forecasting models, most of which have at least some discrete choice sub-model (e.g., mode choice). As mentioned in Section IV.3.2.2, travel forecasting models can perform fairly well to capture to meso-level land use effects. Their ability to account for micro-level effects, however, is fairly limited for at least two reasons. First, the models operate with areal units, the travel/traffic analysis zone (TAZ), that may be incompatible with accurate representations of micro-level built environment traits (discussed further in the next Chapter). For basic travel forecasting, high resolution in the TAZ may be unnecessary (due to possible difficulties in forecasting detailed aspects of a given zone, much less the individuals and households within them) but also highly expensive and data intensive (Ortúzar and Willumsen, 2001). Furthermore, TAZ construction will generally follow some other relevant administrative unit (e.g., census zones) for data validation, etc. – which, again, may not reflect the characteristics of the built environment (e.g., boundaries may arbitrarily influence built environment characterization; the MAUP, discussed in the following Chapter). Indeed, a common TAZ objective is to define spatially homogeneous areas, which may complicate efforts to measure the influence of truly “mixed use” areas.

Another problem in using forecasting models to estimate micro-level effects comes from their inherent inter-zonal (inter-TAZ) focus. The models aim to predict aggregate flows among TAZs, but cannot necessarily account for what might make trips stay within a TAZ or what within the TAZ may influence travel behavior. In this regard, the LUTRAQ project (see Section IV.3.2.2) again seems to be a pioneer, through efforts to introduce the influence of development density and a measure of pedestrian amenity (the pedestrian environment factor, PEF<sup>81</sup>) into the various modeled choice decisions (auto ownership, pre-mode choice, mode choice) (Rosenbaum and Koenig, 1997). More recent efforts have followed the Ewing and Cervero (2001) elasticity approach, essentially via “post

---

<sup>80</sup> This is without even going into broader questions about choice-decisions; whether people are capable of perceiving or even knowing the actual attributes of the alternatives.

<sup>81</sup> A subjectively derived score that aims to reflect, in the zone, the: ease of street crossings, sidewalk continuity, street connectivity (grid versus cul-de-sac), and topography.

processing.”<sup>82</sup> The basic idea behind post-processing is that forecasting model results can be adjusted, so that the supposed TAZ-level influences that the forecasting model cannot account for will still be reflected in forecasts by applying generalized elasticities (similar to those in Table IV-5). The approach has several advantages, such as not requiring extensive model re-calibration or validation; but it also suffers from severe shortcomings, such as the failure to capture potential feedback among the relevant sequential steps (e.g., trip distribution, traffic assignment) (see, PBQD, 2000). Despite these shortcomings, the approach has been employed in Atlanta (see Walters, et al. 2000), to assess a land development project that subsequently was awarded trip reduction/air pollution credits (U.S. EPA, 2001). Swenson and Dock (2003) demonstrate how the approach can be used in adjusting intrazonal and inter-zonal trips in the traditional four-step modeling framework.

A purely micro-scale simulation in the travel forecasting tradition can be found in McNally and Ryan (1993) who are interested in looking at the implications of simply the road layouts implied in a neo-traditional development versus a more conventional suburban development. They take a hypothetical development of 108 acres, and make very little variation in implied land allocation (types of uses, location of those uses). Using conventional trip generation rates, and distribution and assignment procedures, they assess the performance of the internal (i.e., to the development) road network and find the neo-traditional network results in shorter travel distances, with improved volume/capacity measures as well (and negligible impacts on intersection levels of service). The authors point to the need to link such analyses to regional modeling efforts.

#### *IV.3.3.4 Comments*

The micro-scale evidence reveals, more than anything, that despite a continuously-growing body of research and increasingly sophisticated analytical techniques, we still cannot make any conclusive, generalizable statements about the role of urban design on travel behavior. This inconclusiveness owes itself in part to the lack of consistent, behaviorally-rigorous analyses (as suggested, e.g, by Crane, 2000). Additional interpretative problems come from the variety of analytical techniques used and possible data differences, including those arising from variation in survey instruments and potential variation in types of trips counted. In some cases, the spatial scale or built environment measures remain vaguely defined. Furthermore, the variety of travel outcomes measured (mode choice, number of trips by a given mode, total trip rate, trip time, etc.) only further complicates conclusions. This relates back to the call for improved transportation performance indicators that truly represent meaningful outcomes (travel time, travel distance, accessibility?), but that also represent actual behavior (e.g, trip chaining). Both Srinivasan (2001) and Krizek (2003a,c) offer explorations in this area. Finally, it may well be possible that, as Handy (1996) declares, the impacts are “different in every context” (p. 196).

Except for the most recent approaches (inspired by the “Crane School”), very few analyses actually control for transportation levels of service, which clearly play a major

---

<sup>82</sup>Cervero (2002) also calls for the use of elasticities derived from, apparently, micro-level effects to be used in forecasting model “post-processing.”

role in determining travel choices. Many of the studies do not even control for income effects (e.g., Holtzclaw et al, 2002), which also have an important role. It seems, in general, that analyses based on aggregate data (e.g, IBI Group, 2000) tend to reveal more conclusive (and dramatic) results than those based on disaggregate data; this may be a sign of ecological fallacy. Along these exact lines, Handy (1992) calls for disaggregate analyses, noting that average effects mask local variation (see, also, Pas, 1978). She also suggests the need to focus on more than a single day's travel; this would be particularly important to capture broader possible effects related to potential constant travel time budgets (as detected by McCormack, et al [2001] in the Seattle neighborhoods and suggested, more globally by Schafer [2000]) and trip substitution behavior (longer trips for shorter trips, either inter- or intra-urban). Both Handy (1992) and McCormack et al (2001) point to the need for local effects to be examined in the broader regional context (i.e., at the meso-scale).

Recent efforts (e.g., Greenwald, 2003) show signs of increasing econometric sophistication, but this seems to come at the cost of almost further complicating the possibility to comprehend results. Furthermore, it seems like a somewhat unnecessary complication to modeling a process (e.g., mode choice), for which well-established modeling techniques already exist.<sup>83</sup> Finally, we need to keep in mind that most of these studies still end up using TAZ-level areal units to represent effects (due, in many cases to data availability – such as travel survey data only geo-coded to a TAZ). The possible implications of this are discussed further in the following Chapter.

#### **IV.4 Conclusions**

More than thirty years ago, a review of the studies of the influence of land development patterns on travel demand, found an “unclear and somewhat contradictory picture” in part due to “different methodologies and assumptions used in the analyses” (Gilbert and Dajani, 1974; p. 271). Twenty years after that assessment, another review of the influence of urban form on travel demand and emissions concluded that “our current level of understanding is relatively weak” (Anderson et al., 1996; p. 29). A number of subsequent reviews in more recent years make, essentially, similar conclusions, pointing out theoretical shortcomings, weaknesses in methodologies, and problems with data availability and quality and/or model specification (e.g., Crane, 2000; Badoe and Miller, 2000; Cervero, 2002). In many ways, it seems that we have not come very far in over three decades.

Despite that pessimistic appraisal, we can make some generalizations, with the degree of confidence in the results basically increasing with the spatial scale of analysis. At the Metropolitan-scale, drawing primarily from inter-city comparisons, there seems to be

---

<sup>83</sup> For example, Greenwald (2003) first estimates substitution rates between modes (e.g., transit and drive) for different trip types, using OLS. He then uses these substitution rates in a second stage model (Tobit) to predict influences on mode choice (e.g, transit vs. drive). This leaves one with the question: why not simply go to the mode choice (e.g, logit) framework which captures those substitutions more elegantly and intuitively. The question is even stronger when one considers that the explanatory power of the models becomes virtually random: e.g., R-square for OLS of 0.03, with the results still being fed into a second stage model (Tobit), which also displays fairly low measure of goodness of fit.

good evidence showing the link between total urban area and, *ceteris paribus*, total intra-city passenger travel (e.g., Cameron, et al, 2003). At the intra-metropolitan scale, factors such as the degree of urban poly-nucleation and relative distance to the central business district (consistent with the metro-level total urban area finding), seem to reveal consistent influences. At the micro-scale, however, the picture becomes murkier; local mixing and density does apparently influence mode choice, although the impacts on overall travel are basically indeterminate. Furthermore, in practice the micro-scale and meso-scale influences may not be truly separable; for example, local-level effects may have no influence without relevant meso-scale characteristics, while meso-level influences such as relative densities or mix of uses may only be possible with particular micro-level design characteristics (e.g., certain street widths and block sizes).

Perhaps the most notable development in recent years has been the push to base the relevant research within more rigorous behavioral theories. Crane (e.g., 1996) should be, at least partially, credited with this push, which, after all, closely aligns with “traditional” transportation systems analysis (e.g., Ben-Akiva and Lerman, 1985). Most notably, recent years have seen analysts make the explicit turn to discrete choice models (e.g., Srinivasan, 2000; Zhang, 2002; Rajamani, et al., 2003). Such analyses reveal mixed assessments of land use effects, particularly in comparison to other influencing factors. Rajamani et al (2003), for example, looking at the Portland (Oregon, US) case show that household and individual socio-demographics tend to dominate urban form measures, except for bus stop access for transit mode choice and land use diversity for walk choice. For the Boston case, Zhang (2004) shows that, for work trips, travel cost influences dominate land use measures, except for density effects on non-motorized mode choice and network connectivity for the shared ride option; he found similar results for non-work trips. Other recent relevant analyses (e.g., Rodriguez and Joo, 2003; Cervero, 2002) do not readily enable a direct comparison of the effects of built environment variables versus socio-demographic characteristics.

Several challenges remain within this field of research. One relates to the type of data typically used – trip-based household travel surveys for a single day (often a typical work week day). Data in this form make it difficult to assess broader travel impacts, including weekly shopping habits, recreational travel, and trip-chaining propensity. These issues are linked to the idea of the constant travel time budget (e.g., Schafer, 2000); McCormack et al (2001), for example, find consistent travel time budgets among Seattle neighborhoods of differing types. Such results have a clear sustainability link, especially if shorter distance, intra-urban travel leads to longer-distance inter-urban travel. Such impacts have not been the focus of much research, in part because the data simply is not there.

Perhaps more fundamentally, however, is the problematic issue of “self-selection.” Self-selection refers to the fact that the related empirical work aims to measure individual and/or household travel behavior under the assumption that the built environment influences that travel behavior. The possibility may well exist, however, that people/households choose their location based on the travel behavior they prefer and, thus, they “self-select” into those locations. Note that self-selection may operate at the

Metropolitan scale (i.e., all else equal, a household may prefer to live in a city with better/worse public transport service than another); the meso-level scale (i.e., a household may prefer one area of a metropolitan region than another); *and* at the micro-level scale (i.e., preference for a specific neighborhood type versus another). In these cases, travel behavior is the cause, not the effect, of the household's location choices and we would be inappropriately "crediting" land uses for producing outcomes that were more truly a result of individuals' and households' travel preferences. Several innovative research approaches to dealing with this issue have produced somewhat varying results. Meurs and Haaijer (2001) and Krizek (2003c), for example, use longitudinal panel data (following households in time) to find some evidence that travel behavior does change with a household's change in local design characteristics. Kitamura et al (1997), using specifically designed household surveys, found that people's attitudes are more strongly associated with travel land use characteristics, suggesting the need to change residents' attitudes together with land use patterns. Similarly, Bagley and Mokhtarian (2002), using a system of structural equations, find that attitudinal and lifestyle variables dominate travel demand, while residential location type had little impact. Others have used various econometric techniques, such as instrumental variables (e.g., Boarnet and Crane, 2001b; Khattak and Rodriguez, 2005) or probabilistic self-selection approaches (Greenwald, 2003). Generally, the evidence suggests that self-selection does exist (e.g., Khattak and Rodriguez, 2005), but that some built environment effects can be detected even after accounting for self-selection.

Ultimately we must face the reality that we are aiming to understand effects within a complex system involving family life-cycle (e.g., single, household with no children, retirees, etc.), automobile ownership decisions, etc. This has led some researchers to suggest that the proper analysis of the impacts of urban form on travel behavior requires a fully integrated urban model (Badoe and Miller, 2000). While that might be the case, such a model still requires clearly understood and measured empirical effects to properly calibrate behavioral functions. This, then, leads us back to the question of whether or not there are any meaningful behavioral effects to tease out. Answering this question continues to be important, particularly in the face of rapid urbanization and growth in travel demand. If we look simply at potential technological fixes, the evidence supports a need for some demand management, at least into the medium term. For example, Heywood et al (2003), assessing the energy consumption impacts of plausible vehicle technological improvements in the US market, end with the "sobering overall conclusion" that technology improvements *and* reductions in travel growth are critical. This does not suggest that technological improvements should not be pursued – clearly they should. But, such improvements will not "solve" the problem on their own, particularly when we recognize the broader range of relevant impacts and the fact that the city we build today dictates the city inhabited in the future. Can a city's structure, form and design contribute to more sustainable transportation and, in turn, a more sustainable city?

## V

### MEASURING URBAN FORM, DESIGN AND NEIGHBORHOODS

One of the challenges to interpreting coherently the meso- and micro-level analyses of the influence of the built environment on travel behavior reviewed in the previous Chapter comes from the sometimes unclear and/or quite often inconsistent definition of the type of built environment measures used, their scale (or at least their degree of spatial aggregation) and what, then, they propose to actually capture. Population density serves as a simple, but illustrative, example. First, population density is not actually a measure of the built environment at all, rather it is a demographic variable that might – or might not – be a good proxy for the built environment (depending on the scale at which it is measured); furthermore, analysts often leave it unclear whether they are using net or gross population densities (a point raised by Kain (1967) nearly four decades ago). In addition, the studies often vary in terms of what they consider the “built environment.” For example, the number of bus stops or the proximity to highway exits does not necessarily represent physical characteristics of the city; more properly they are proxy variables for transportation levels of service. This Chapter provides a review of the major issues involved in attempting to measure the built environment from the travel behavior perspective.

#### V.1 Challenges to Measurement

Hess et al (2001) identify several shortcomings related to attempts to construct variables that can define the built environment for the purpose of assessing effects on travel behavior, including:

- Untested proxy variables. For example, there is a lack of empirical testing of how well available variables actually capture the relevant attributes of the built environment.
- Variables that capture heterogeneity instead of the complementarity of land uses. For example, entropy indices (which aim to measure the balance of uses in a given zone relative to the overall area of study) cannot differentiate between a zone with a high concentration of uses because of a large presence (e.g., a shopping mall) versus a zone with “many smaller interspersed pockets” and they also weigh all land use types equally (even though, for example, the share of office vs. industrial has different implications than an equal share of office vs. residential).
- The poor spatial boundaries related to data availability versus actual development patterns. For example, where boundaries are drawn for any geographic unit of analysis can significantly affect the variable’s value (e.g., density).

##### V.1.1 The Modifiable Areal Unit Problem

The last point above relates directly to the well-known problem in the analysis of spatial phenomenon, the so-called modifiable areal unit problem (MAUP). The MAUP basically has two aspects, scale and unit definition (Horner and Murray, 2002). Scale refers to the fact that the scale of analysis can be changed via the aggregation of areal units (e.g., from blocks to census tracts). Unit definition (the “zonal effect”), on the other hand, refers to the multiple number of possible areal units within which an area of analysis can be

defined. These effects have been shown to influence relevant quantitative and statistical analyses. To reduce the possible bias associated with the MAUP, areal units should be consistent with the phenomena of study, meaning we need to know the appropriate number of zones (scale) *and* their appropriate configuration (unit definition) (Horner and Murray, 2002).

**Table V-1 Spatial Units of Analysis in Several Recent Studies**

Study	Purpose	Areal Unit of Analysis
Krizek (2003)	Measure of <i>Neighborhood Accessibility (NA)</i>	150-meter grid; with measures calculated at a moving average of adjacent cells
Rajamani et al (2003)	Land use measures in mode choice model	Census block group boundary (assumed to represent <i>neighborhood</i> )
Srinivasan (2001)	BE in demand models to assess influence of " <i>neighborhood</i> "	Travel survey is coded to TAZ; BE measures developed at other levels, but aggregated to TAZ
Rodriguez & Joo (2004)	BE on mode choice	Block group for density; corridor measures for path, slope, sidewalk
Cervero (2002)	BE on mode choice	TAZ
Zhang (2004)	BE on mode choice	TAZ; 800-m grid
Cervero & Kockelman (1997)	BE on Travel Demand	Census tract as <i>neighborhood</i> (sometimes joined when not enough survey information in one tract); 1 Hectare grid
Crane & Crepeau (1998)	BE on Travel Demand	Match HH address by telephone no., buffer 1/2 mile around HH to measure network; census tracts for land uses
Hess & Ong (2002)	<i>Neighborhood</i> on Auto Ownership	TAZ, census tracts
Greenwald (2003)	BE on Nonwork mode substitution	TAZ as <i>neighborhood</i> (implicit)
Greenwald & Boarnet (2001)	BE on walk	TAZ, Block Group, HH buffers (1/4 -1 mi)
IBI Group (2000)	Avg. HH Transport GHG Emissions per TAZ	TAZ; in some cases TAZ centroid radii

Notes: BE-built environment; TAZ-travel analysis zone; HH-household; GHG-greenhouse gases

The implications for understanding the influence of land use on travel behavior (or any aspect of travel behavior) are fairly clear, particularly when we aim to discern micro-level effects (if, indeed, they exist). Basically, we do not know if TAZs – the typical spatial unit of analysis – offer an adequate representation of the number of zones or an appropriate configuration (of those zones) to determine potential local-scale effects. Despite this fact, the TAZ, or similar administratively-defined spatial areas (such as block groups) remain a very common base unit for measuring micro-effects in the relevant analyses (see Table V-1).

Spatial aggregation to the TAZ, while historically critical for analytical and computational tractability, can hamper micro-scale analysis for multiple reasons. For example, TAZ boundaries may be drawn in ways that slice neighborhoods and/or combine various neighborhood types (see Figure V-1), thereby limiting the possibilities to capture possible micro-level influences (such as pedestrian amenities, or local mix of land uses) on travel behavior. So, TAZ structure not only means that short trips (by any mode) may well be poorly estimated, but also that the influence of local-level urban form factors on travel behavior may well be lost. In short, TAZ-based analysis of micro level effects is almost certainly susceptible to problems related to the MAUP.

**Figure V-1. What TAZ Do You Live In?  
TAZ Boundaries and Block-level Dwelling Unit Densities (Santiago)**



#### V.1.1.1 The MAUP in Transport Analyses

Somewhat surprisingly, few studies in transportation specifically deal with the MAUP. Ding (1994) looks at the problem in the context of TAZ variations in forecasting, while Horner and Murray (2002) look at the problem as it relates to estimates of “excess commuting.” Zhang and Kukadia (2005) recently explored the MAUP as it relates specifically to the influence of the built environment on travel behavior; they find evidence of both a scale and unit definition (zonal) effect. Basically, they find the coefficients on the relevant variables (in a multinomial logit model of mode choice) to vary depending on the spatial scale (degree of aggregation – e.g., from block to block group to TAZ) and depending on the zonal construction (e.g., 2-mile grid cell versus TAZ). Their analysis leads them to two relevant, and related, conclusions: (1) aim to use behaviorally-based scales and unit definitions and (2) an 800x800 meter grid cell seems

to be appropriate in minimizing potential bias from MAUP in relevant analyses.<sup>84</sup> The grid-cell has often been identified as a possible means of dealing with the MAUP (e.g., Robson, 1969<sup>85</sup>).

Zhang and Kukadia's (2005) conclusions have important implications for the relevant research. Regarding their recommended grid-cell approach and the analysis that brings them to this recommendation, *they basically find a decreasing degree of detectable effect* (measured by the size of the coefficient) as the unit of analysis shrinks: for population density, the influence is on NMT (bike and walk) mode choice and for land use balance the influence is solely on walk. Importantly, for land use balance, no detectable effect occurs below the ½-mile grid cell. While the authors do not make this observation, to me it seems to indicate that no relevant micro-scale effect seems apparent, which means traditional forecasting techniques might be appropriate (after all, the trip distribution stage explicitly accounts for relative distribution of land uses). For population density, the effect also diminishes, although significant influences are still detectable at a very small scale (the 1/16<sup>th</sup>-mile grid cell). This reflects some micro-level influence that forecasting models might not otherwise capture.<sup>86</sup>

Zhang and Kukadia's conclusion on "behaviorally-based" areal definitions has a theoretical attractiveness and is consistent with, for example, the U.S. Census Bureau's "User Defined Areas Program," which aims to match local perceptions of "functioning social areas" with the process of aggregating data from the census block up (Sawicki and Flynn, 1996). But, behaviorally-based definitions face clear practical challenges in terms of built environment-transportation analyses. Upon what sort of behavior should the areal unit be defined? The average walk distance? The apparent trip-shed for a given household? Some more complex interaction space? A risk of tautology exists here; for example, if we were to define the basic areal unit based on households' average trip distances (which is obviously influenced by the built environment to some degree) and then we use that areal unit to then attempt to capture the influence of the built environment on travel behavior, haven't we just defined the extent of the effect?

## **V.2 Analyzing Effects: Built Environment Measures or Neighborhood Units?**

In the micro-scale analyses reported in the previous Chapter (Section IV.3.3), the approaches of capturing urban design effects differ in a subtle, but fundamental way. Some attempt to measure the influences of various indicators of urban design, such as population density, dwelling unit density, land use mix, etc. (see, e.g., Table V-2). This follows along the line of thinking of some, like Crane and Crepeau (1998) who claim the need to evaluate "the contribution of each characteristic individually" (p. 226). On the

---

<sup>84</sup> They also justify this second conclusion in light of the first, by noting that this grid cell size – equivalent to an area with approximately a ¼-mile radius – matches the conventional definition of a "transportation impact area."

<sup>85</sup> Robson, writing before the formal "coining" of the term MAUP, says: "the grid-square principle would solve many of the technical problems confronting the use of areal data."

<sup>86</sup> They find a decreasing effect for road network also, with no detectable influence under ¼ mile; the coefficient, however, is not significant.

other hand, other research has focused on the influence of the neighborhood (in aggregate) (e.g., Cervero and Gorham, 1995; Cervero and Radisch, 1996; McNally and Kulkarni, 1997; Khattak and Rodriguez, 2005). Some research combines the two analyses; Cervero and Gorham (1995), for example, detect that individual measures of urban form (density) exhibit different influences on travel behavior depending the neighborhood type (i.e., “auto” versus “transit” neighborhood).

### **V.2.1 Built Environment (BE) Measures**

In early analyses of the influence of urban form or design on travel behavior, population density and employment density served as the principal indicator representing urban form (e.g., Kain, 1967; Sammons and Hall, 1977; Cheslow and Neels, 1980). In these cases, density basically served as a proxy for other potentially influencing variables. But, from a policy or design perspective, density on its own does not always offer effective guidance: highly dense areas may or may not effectively influence travel patterns and may well act in concert with other factors (such as street layout, urban amenities, etc.) to influence outcomes. Today, one can find a wide range of variables included in analyses: street design and circulation patterns; mixes of land uses; distance between land uses; etc. (see, e.g., Chapter IV’s Table IV-3 and Table V-2). Many authors have derived different techniques to try to measure land use mixes, such as the entropy index (apparently first derived in this type of analysis by Cervero, 1989; also used by Cervero & Kockelman, 1997, Srinivasan, 2001; Zhang, 2004) and various types of “dissimilarity” or “diversity” measures (see, e.g., Rajamani et al, 2003; Kockelman, 1997; Srinivasan, 2001; Greenwald, 2003).

Dill (2004) provides a comprehensive review of the various types of *network connectivity* measures that have been employed, drawing from the transport, geography, urban planning and landscape ecology fields. Relevant block measures include length, size and density, area; street measures include street density, intersection density or percent intersections of certain types, and basic street style (e.g., grid-street dummies); general connectivity measures include link-node ratios or connected node ratios. In her application of four measures to Portland, Oregon, Dill (2004) finds that the measures do not consistently produce the same levels of connectivity to a given area. In some way, the link-node connectivity measures reflect a basic theoretical similarity to the “space syntax” school of urban morphological measurement (e.g., Hillier and Hanson, 1984). Somewhat interestingly, while “space syntax” has seen widespread use, particularly in Europe, few (if any) examples exist of its application to the built environment-travel behavior analyses in the U.S. Space syntax remains somewhat polemical as an “objective” approach to measuring the built environment (e.g., Ratti, 2004a,b; Hillier and Penn, 2004). Ratti (2004a,b) exposes some apparent conflicts in, and potential loss of information from, space syntax’s foundational “axial map” techniques. Batty and Rana (2002) demonstrate that no unique axial map algorithm exists, so that very different measures can be derived based on the same principles for the same area. This result thus suggests potentially inconsistent measures, similar to Dill’s (2004) finding.

**Table V-2. Micro-Level Built Environment Measures in Recent Relevant Studies**

Study	Density	Diversity	Design
Krizek (2003b)	Housing Unit; Persons	Employees in local convenience businesses (general merchandise., food, misc. retail, eat/drink)	Block size
Rajamani et al (2003)	Population; %HHs w/in walking to Commercial	Distribution Quotient; Land use diversity measure	Connectivity Index (links/nodes); % cul de sacs
Rodriguez & Joo (2004)	Population		Walk/bike path availability, slope, sidewalk presence
Cervero (2002)	Population+Employment/TAZ area (At O&D)	O & D normalized entropy index; relative pop+empl share to countywide	Ratio of sidewalk miles to road miles; proportion of multi-family DU w/in 1/2 mile of rail station
Zhang (2004)	Population and jobs density at TAZ O&D	800-meter grid cell Entropy index for land use balance at O&D (residential, commercial, industrial)	Percentage of cul-de-sac intersections at O&D (TAZ);
Crane and Crepeau (1998)	Census tract share of residential use	Census tract share of commercial use; census tract share of vacant use	Connected street pattern, street network density, mixed street pattern
Hess & Ong (2002)	HH Density	Land use mix in TAZ (total emp/total HH)	Pedestrian environment factor
Greenwald (2003)	Total employment density; Retail employment density	Mixed use index	Number of intersections; Average parcel size
Greenwald & Boarnet (2001)	Pop (BG and ZIP); Retail Emp (1 mi and ZIP)		Percentage Grid 1/4 mi; PEF in TAZ

Notes: TAZ-travel analysis zone; HH-household; O&D-origin and destination; DU-dwelling unit; PEF-pedestrian environment factor; BG-block group; ZIP-zip code.

#### *V.2.1.1 Capturing Multidimensionality*

Improved data and improved software (particularly the growth in use of GIS) have led some analyses to include larger numbers of potentially relevant BE indicators. Cervero & Kockelman (1997), for example, identify 22 variables within their now well-known “3 D’s” of the built environment: density, diversity and design. They collect these variables for 50 areas across San Francisco and use factor analytic techniques (see Appendix) to reduce these many variables (due to inevitable multicollinearity) into two interpretable factors from 12 variables: *Intensity*, which represents variables such as retail store density, park intensity, population density; and *Walking Quality*, which includes street light provision, block length, sidewalks. These factors prove to be varyingly significant in several different models of mode choice for different trip types and the Intensity Factor also figures significantly in non-work VMT per household. Other BE variables on their own figure into some of their models, particularly the proportion of *4-way intersections*.

Notably, the authors conclude that – “despite very time-consuming field work” – *relatively few micro-scale built environment factors had a significant influence on travel demand once broader measures were accounted for.*

Srinivasan (2000, 2001, 2002) also uses factor analysis techniques in her analysis of the Boston metropolitan area. She develops 50 variables, measured at the TAZ level, which measure the built environment (e.g., road configuration and various land use entropy measures) and accessibility (measured, e.g., via transit and auto travel times to different land uses) and derives 8 representative factors, relating to the character of place (e.g., “suburban character”, commercial-residential mix and balance) and transportation service (e.g., highway proximity, pedestrian convenience). She finds several of these factors to be significant in various models to predict trip-chaining propensity and incremental travel time increases. Krizek (2003b), building on three “tenets” that basically match Cervero and Kockelman’s 3Ds, also uses factor analysis in an attempt to boil three different urban design measures (see Table V-2), into a single measure that he calls “neighborhood accessibility.” He then goes on to find this measure to be statistically significant in various models predicting personal and vehicle miles traveled and trip-making and trip-chaining propensity (Krizek, 2003c).

The factor analytic techniques basically aim to capture the multiple and inevitably inter-related aspects that comprise the micro-scale effects that may influence travel. The results, however, do not necessarily translate into ready policy applications. Cervero and Kockelman (1997), for example, calculate an estimated elasticity of non-work VMT with respect to the “intensity factor” of -0.063. This factor, however, is comprised of 6 actual variables, each with different relevant factor loadings; so it is difficult both to understand how much the various variables might have to increase to make a discernible effect. Furthermore, factor analysis techniques – despite a long history of use in relevant social sciences (see the Appendix) – remain controversial, as results depend critically on decisions of basic variables included, the models used (e.g., principal components), rotational techniques employed, factors retained, etc. Sound theory should guide these choices and careful steps should be employed in application (e.g., Gorsuch, 1983); if not, results can easily become erroneous or ambiguous (e.g., Preacher and MacCallum, 2003). In most of the published use of factor analysis discussed above, it is difficult to gauge the degree of adherence to sound application; Srinivasan’s dissertation (2000) displays a thorough and rigorous treatment of relevant techniques.<sup>87</sup>

Nonetheless, some means of capturing the multiple effects and their interactions seems important. In his analysis, Greenwald (2003) finds that the natural log transformation of land use variables provide the appropriate form for inclusion in a travel demand model.<sup>88</sup> This logarithmic transformation suggests a multiplicative, not additive relationship among urban form variables.<sup>89</sup> In other words, “the whole is more than simply the sum of

---

<sup>87</sup> This is not to say that the other approaches mentioned did not adhere to rigorous application; however, being in a dissertation, Srinivasan’s (2000) analysis provides careful and thorough documentation.

<sup>88</sup> His model is a prediction via OLS of substitution rates for different modes (e.g. walk versus driving; transit versus driving); residual analysis of the land use variables suggested a log-linear relationship.

<sup>89</sup>  $y = \ln a + \ln b + \ln c \rightarrow e^y = e^{(\ln a + \ln b + \ln c)} \rightarrow e^y = e^{(\ln a)} * e^{(\ln b)} * e^{(\ln c)} \rightarrow e^y = a * b * c$

its constituent architectural parts” (Greenwald, 2003; 52). In this sense, then, perhaps the variable-oriented approach is mistaken, should we be looking, more specifically at the neighborhood “in its whole?”

### V.2.2 “Neighborhood”-Oriented Approaches

The idea of “neighborhood” is implied or explicit in many of the studies that take a variable-oriented approach to measuring urban form (see Table V-1). In other words, researchers say they will focus on the “neighborhood scale” effects and then aim to measure variables at that scale, often reverting to the TAZ or groups of TAZs (e.g., Cheslow and Neels, 1980; IBI Group, 2000; Holtzclaw et al. 2002), the TAZ, census tracts and areas immediately surrounding households (e.g., Boarnet and Sarmiento, 1998; Greenwald and Boarnet, 2001), other combinations (e.g., Srinivasan, 2001; Zhang, 2004), or sometimes completely new geographies (e.g., Krizek, 2003b). The analyses then continue in a cross-sectional way to tease out BE effects, as discussed in the previous Chapter.

In contrast, other researches have taken a comparative, in many cases “*quasi-experimental*” design, approach. In these cases, the “neighborhood” in its entirety is expected to influence travel behavior. As such, instead of focusing on particular, somewhat arbitrary measures, like TAZ density, the analyses focus on neighborhoods, or neighborhood types, such as neo-traditional, conventional suburban, auto- or transit-oriented, etc. Some practical attraction exists here: if the goal is to dictate policy (or investments), perhaps we can more effectively communicate particular neighborhood types (e.g., neo-traditional) as opposed to more abstract metrics (e.g., diversity index). The approaches can be used in combination.<sup>90</sup> For example, the IBI Group (2000) identifies the basic built environment variables that apparently influence travel demand in Toronto; but then to aid policy interpretation (i.e., potentials for greenhouse gas emission reductions), they typify the neighborhoods according to basic network and land use characteristics (Table V-3) (as well as distance from the traditional CBD).

**Table V-3. Basic Characteristics of Development Types in Toronto, Ontario**

<b>Development Type</b>	<b>Units/ hectare</b>	<b>Uses</b>	<b>Transport Network</b>
<b>Conventional Suburban-Style</b>	3.6	Single-use (residential)	Wide, curvilinear, discontinuous, long NMT distances
<b>Medium-Density</b>	21	Some mix of uses	Mostly curvilinear, increased connectivity, some NMT facilities
<b>Neo-Traditional</b>	43	High mix	Grid circulation, short blocks, narrow streets

Source: IBI Group, 2000.

Many examples of comparative neighborhood approaches exist. Handy (1992, 1996) cross-classified areas based on regional/local accessibility measures and chose neighborhoods, ranging in size from 1 to 4 sq. miles (in Greater San Francisco) based on

<sup>90</sup> In reality, even in the specific neighborhood approach, measures of built environment are generally compiled to provide indicators of the representative BE characteristics.

the resultant categories. Cervero and Gorham (1995) chose neighborhoods, ranging in size from ¼ to 2¼ square miles, in southern and northern California (Greater San Francisco and Los Angeles, based on street maps, transit service information, and residential densities. Cervero and Radisch (1996) chose “two distinctly different neighborhoods” in the San Francisco area, aiming to control for relative location, incomes, transit service and freeway access while still comparing a “traditional” compact mixed-used neighborhood with a Post-WWII suburban-style community (the neighborhoods are represented by dummy variables in choice models). Kitamura et al (1997), also looking at the San Francisco Bay area, chose their neighborhoods from TAZs as the basic areal unit and then looked for extreme variations in land use measures, carrying out site visits, and finally arriving at five different neighborhoods of about 1 square mile each.<sup>91</sup> Handy et al (1998), selecting neighborhoods for an analysis in Austin, TX, drew from existing boundaries (i.e., neighborhood associations), and then used two basic additional criteria – age of development (assumed a good predictor of urban design characteristics) and relative location – to choose case study neighborhoods. Built environment characteristics of those neighborhoods were then derived, representing the transportation network, commercial activities, and design characteristics. While they classify neighborhoods generally as “traditional,” “early modern,” and “late modern,” they also note that both within-class differences and across-class similarities can be found.

This latter observation is consistent with the findings of Bagley et al (2002) who use factor analysis techniques (discussed above) to try to assess residential area type, including variables such as speed limits, grid-like street configuration, population density, distance to stores, public transit convenience, among others. They claim to find something of a “traditional-suburban” characteristics space, within which neighborhoods can score high or low on both dimensions.<sup>92</sup> Song and Knaap (2004) also employ factor analysis and cluster analysis (on subsequent factor scores) in an attempt to develop “statistically defined” neighborhood types among new homes developed in the Portland (Oregon) metropolitan area. Their analysis leads them to identify 6 neighborhood types, which fundamentally vary by design dimensions, but can be categorized across the city based on relative location (e.g., rural, suburban).<sup>93</sup> Finally, McNally and Kulkarni (1997) also take a “data-driven” approach to neighborhood characterization. They select – apparently based on TAZs (a “subjective assessment of what constitutes a spatially recognizable neighborhood”; p. 107) – 20 neighborhoods for analysis in Orange County (CA). They proceed to classify the neighborhoods by network attributes and land use attributes, based on these attributes’ “perceived importance,” using K-means cluster analysis to identify neighborhood “themes” (see Table V-4), with further distinctions

---

<sup>91</sup> Unlike the other studies in this paragraph, Kitamura et al (1997) do not use the neighborhoods, themselves as differentiators; rather they use the neighborhoods defined in the process described to identify potential survey respondents and to also develop the relevant land use descriptors.

<sup>92</sup> As discussed in the Appendix, there are some questions regarding the applicability of factor analysis in this case, particularly due to the large number (10) of binary variables used; the factor analysis literature seems somewhat divided on the appropriateness of using such variables (e.g., UT-Austin, 1995; Kubinger, 2003).

<sup>93</sup> Again doubts about the appropriateness of the factor analysis application can be raised in this case; see the Appendix.

made based on additional attributes (e.g., density of single family residential area, strip commercial area, etc.). McNally and Kulkarni (1997) consider that their approach produces quantitative distinctions, which reflect “real developments and the design movements that inspired them.” (p. 110).

**Table V-4. “Neighborhood Themes” in Orange County, California**

<b>Neighborhood Theme</b>	<b>Transportation Network</b>	<b>Land Use Traits</b>
<u>Planned Unit Developments</u> (PUDs; the “quintessential suburb”)	Many cul-de-sacs, limited access points to neighborhood	Segregated land uses, low residential densities
<u>Neotraditional Neighborhood Design</u> (TND)	Grid-like street network, few cul-de-sacs, many access points	High population density, lower than average residential uses, higher than average commercial uses
<u>Hybrid</u> (MIX)	Many cul-de-sacs, but also grid arterials	Large amount of single family homes, but higher than PUD densities, and more commercial uses

Source: McNally and Kulkarni, 1997.

*V.2.2.1 Urban Design-Based Approaches and Other Perspectives on Neighborhoods*

McNally and Kulkarni’s (1997) conclusion on reflecting “design movements” reminds us that we cannot ignore the strict urban designers’ perspective. In identification of neighborhoods, Lynch (1984) discusses the scale of the “local unit” and the relevance of size (in terms of number of households) and the role of street patterns and “common services,” but also notes social interactions, social homogeneities, and “identity” of boundaries. Southworth and Owens (1993) also note the fundamental importance of size, differentiating between communities and neighborhoods, with the latter, by their account, consisting of roughly 100 acres (2000 feet across), requiring no longer than 10 minutes to traverse by foot. Those authors formulate neighborhood typologies according to prevailing street patterns (identifying five basic types) and block- and lot-related characteristics (including street widths, lot size and shape, and building types). In a somewhat similar approach, Moudon (1992) suggests a typology of residential forms in the United States building from house and lot types (4 different types) and street layouts (3 basic types, plus two hybrids). Finally, Talen (2003), inspired by Lynch, suggests that urban characterization should build from a “normative” framework – what cities should be. This leads her to propose elements for characterization, such as “enclosure,” “lost space,” “suitability,” “proximity” and “mix.”

Finally, we need to recognize that the physically-based neighborhood typologies discussed here certainly do not offer the only means of neighborhood identification. Neighborhoods have been examined as political economy-units in the tradition of Coase’s theory of the firm (Webster, 2003) and as individual perception-based “externality space” (Galster, 1986), for example. Robson (1969) notes the role of the local area to an individual in terms of comprising an important part of his/her “social world” (p. 241). One might argue in places of high mobility and advanced telecommunications, the role of physical neighborhoods in this regard loses importance to

“virtual” neighborhoods, which include, e.g., professional associations. In this sense, Chaskin’s (1995) differentiation between “communities” and neighborhoods proves useful. He suggests that communities imply some “connection” (shared beliefs, circumstances, relationships, etc), which relate to social networks and social capital, while the neighborhood connotes a clear “spatial construct,” a “geographically bounded unit in which residents share proximity and the circumstances that come with it.” Nonetheless, physical characteristics ultimately interact with social/individual characteristics, influenced by perception and cognition, which suggests something of a fluidity: people’s perceptions change (including via changing demographics) and physical characteristics change; neighborhoods are not permanent in a social, physical or social-physical sense.

### V.3 Conclusions

Measuring the built environment for the purposes of travel behavior research has, in some ways, grown increasingly complex, aided by better data and data processing capabilities. A move from simple demographic-based proxies (i.e., population density) has led to multiple dimensions of analysis that can, generally, be conveniently categorized into Cervero and Kockelman’s (1997) “three D’s”: *density* of uses; *design* of space, and *diversity* of activities. Despite many related analyses, challenges remain. These include the shortcomings identified by Hess et al (2001), such as difficulty in capturing inter-relationships among relevant uses and the fact that actual development patterns might not match to the typical spatial units of analysis for which relevant data might be available. This last point relates directly to the modifiable areal unit problem (MAUP), which tends to be ignored in most relevant research, which ultimately reverts to the TAZ, census block or some other existing spatial unit. Interesting attempts to deal with the MAUP include Zhang and Kukadia (2005).

While individual (or multi-dimensional) metric-based built environment measurement offers one approach to the relevant analyses, neighborhood-based approaches have also been followed, often in a “quasi-experimental” way. Some efforts in this respect have essentially taken existing neighborhoods and attempted to compare them. Others have used various techniques to derive neighborhood typologies based on physical traits. The basic relevant physical characteristics match those often identified by urban designers: physical structure, dictated primarily by road network type (e.g., cul-de-sac, gridiron); building type (e.g., lot size, configuration, unit type); and activities (e.g., types of land uses and the relative mix). Again, one can see a fairly straightforward mapping of these to the “three D’s.” These basic characteristics often then lead to more typologies such as “typical suburban,” “neo-traditional” or hybrid (e.g., McNally and Kulkarni, 1997). These typologies, in meso-space, may well be found throughout the broader metropolitan area (i.e., center city, suburban, exurban).

The idea of using the “neighborhood” as a relevant unit of analysis faces the challenge of neighborhood definition more broadly. The word “neighborhood” reflects a social concept, a spatial concept, and an economic concept. Individual and group cognition and perceptions certainly play a role. Planners will often defer to spatially-based definitions of the neighborhood, which avoid, to some degree, the potentially more complicated

economic or socio-economic concepts. As Chaskin (1995) puts forward, neighborhood delineation will ultimately vary according to the purpose.

Since the research in this dissertation ultimately aims to explore the role of the *physical*, built environment on travel behavior and, it focuses on physical traits to explore local characteristics and aim to detect neighborhood types (Chapter VII). While clearly imperfect, in the face of the other factors that determine the “neighborhood,” this spatially-oriented definition of the neighborhood construct is consistent with most of the large body of research attempting to tease out local “built environment” influences on travel behavior.

## VI SANTIAGO IN CONTEXT

The previous Chapters have laid out the basic sustainable mobility theoretical framework, proposed an operational definition and relevant indicators, and discussed relevant research precedents regarding the influence of the built environment on travel behavior and, more generally, means of measuring the built environment. We now turn to the empirical case. Specifically, this Chapter aims to introduce Santiago de Chile. But, the purpose extends beyond a mere introduction. By situating Santiago within the international, regional, and national contexts, the Chapter intends to enable a better understanding of the potential to generalize from the Santiago analysis to other cities.

### VI.1 Internationally

How to categorize a city in the world web of cities? Hall and Pfeiffer (2000) suggest three city types in the global system: “informal hypergrowth” (e.g., Sub-Saharan Africa, poorer Latin America); “dynamic growth” (e.g., middle income, rapidly developing); and “weakening mature” (e.g., OECD). In this framework, Santiago would clearly fall into the dynamic growth category, characterized by slowing population growth, an increase in population aging, ongoing rapid economic growth, and environmental problems. The World Bank (2002), in its urban transport policy, proposes a simple “city circumstances” categorization framework, within which Santiago would roughly fall into the category of high income/high motorization rate, with low population growth, and a market economy, joining company with cities like Prague (Czech Republic) and Buenos Aires.

Attempting to further generalize a city based on its transportation characteristics becomes challenging, due to data variability, the broad range of cities, etc. Gakenheimer and Zegras (2004) conducted a principal components analysis<sup>94</sup> on the Millennium Cities Database (MCD<sup>95</sup>), as part of an effort to develop an “archetype city” framework based on transportation characteristics alone. An update of that analysis, based on a more rigorous attempt at correctly applying factor analysis techniques suggests five dimensions along which the variables describing a city’s transportation system can vary (see Table VI-1).<sup>96</sup> The results should be interpreted with caution and as tentative (see footnote 96). Beyond the methodological problems with the factor analytic techniques (see Appendix), there are data uncertainties (challenges to ensuring data accuracy and comparability) and issues regarding the sample of cities (in this case, 83 cities across eight regions, but with the major share coming from North America, Asia and Western Europe; see Appendix for additional details). Nonetheless, the results offer an interesting, fairly intuitive, framework for understanding a city’s place in the international “archetype.” A major

---

<sup>94</sup> See the Appendix for details on factor analysis techniques.

<sup>95</sup> Kenworthy and Laube, 2001.

<sup>96</sup> Again, however, as noted in the Appendix; these techniques can be subjective in ultimate application. In this case, I ensured, at least, that all variables included met the measures of sampling adequacy (MSA) test. Nonetheless, in rigor it seems that principal axis factoring would be more appropriate for the approach, as opposed to principal components analysis (see again, the Appendix and, e.g., Preacher and MacCallum, 2003), but problems arose with principal axis factoring (see the Appendix). This suggests a need for caution in the interpretation of the results.

share of a city’s transport system can be explained by its degree of motorization, i.e., “Motorized City” (and accompanying variables related to speed of travel, distances traveled, energy consumption etc.). This component correlates positively with a component that represents some degree of transport externalities and private transport expenditures (i.e., Externalities and Private Costs). The second main component relates to the degree of a city’s NMT and public transport orientation and use (i.e., NMT and Public Transport City), which in turn is partially positively correlated with components representing some degree of transport speed and cost and public transport operating cost recovery (components IV and V).

**Table VI-1. A Principal Components Approach to Typologizing City Transport**

Component	Variance Explained (%)	Correlated With Component	Primary Contributing Variables
I. “Motorized City”	38%	III (+) II,IV,V (-)	Road Length per capita (+), Autos per capita (+), VKM per car (+), Road speed (+), Rail VKM (+), NMT mode share (-), Private transport mode share (+), Avg. trip distance (+), Avg. work trip distance (+), Private transport energy use per capita (+), CO emissions per capita (+)
II. “NMT & Public Transport City”	18%	I (-) IV,V (+)	MC per capita (-), Public transport mode share (+), NMT mode share (+), Private transport mode share (-), Avg. user cost car trip (+), Avg. user cost public transport trip (+), public transport cost recovery (-); % GDP public transport operating costs (+); % GDP on private operating costs (+)
III. Externalities & Private Costs	9%	I (+), V(-)	Density of Rail VKM (-), Public transport mode share (-), Avg. Time public transport trip (+), % GDP on private transport (+), CO per capita (+), Accidents per capita (+)
IV. “Cheap & Slow”	6%	I (-) II,V (+)	MC per capita (+), Taxis per capita (+), Avg. road speed (-), Public transport mode share (+), Avg. Time public transport trip (+), User cost per public transport trip (-)
V. “Efficient City”	5%	I,III (-) II,IV (+)	Cars per capita (-), MC per capita (+), Trips per capita (-), User cost public transport trip (+), Public transport cost recovery (+)

Source: Based on analysis of data from Kenworthy and Laube, 2001; see Appendix for additional details. Components extracted based on Promax rotation, thereby allowing correlation among the components; as such, the percentage explained variance is not cumulative.

Trying to characterize Santiago within these dimensions in a global comparison, we can say that the city is still highly characteristic of a not very “motorized city” (relatively low car ownership and use, short travel distances), although it clearly suffers from an important share of transport externalities (primarily air pollution, at least in part due to its fairly unique topography and meteorology). The city still has a large non-motorized (primarily walk) and public transport mode share, and while it has incurred fairly high capital expenditures on its Metro system, the city maintains a high public transport operating cost recovery (both in the Metro and bus system).

**Table VI-2. Santiago: Basic Mobility Characteristics Relative to Select Industrialized World Cities**

Characteristic	Hong Kong	Singapore	Munich	Stockholm	New York	Phoenix	Perth	Santiago
Population (mns)	6.3	3	1.3	1.7	19.2	2.6	1.2	5.7
Metro GDP/Capita (thousand US\$1995) <sup>97</sup>	23	29	55	33	25	27	22	5.5
Person/Ha	320	93	46	29	18	10	11	80
Autos per 1000	46	116	469	386	444	531	658	145
MCs per 1000	4	43	26	16	10	15	19	3
Freeway length/Cap	13	44	45	130	112	179	43	32
Auto PKT per Person	930	3570	5913	8460	12845	15082	13546	1450
MC PKT per Person	42	217	106	58	19	41	77	46
Public Transport PKT per Person	3675	3143	2622	2317	1266	100	642	2450
Daily Trip NMT Mode Share	34	16	32	28	16	5	9	29-39
Daily Trips per Capita	2.8	2.6	2.7	2.4	3.3	3.6	3.9	2.4-2.8

Sources: Kenworthy and Laube, 2001; Cameron et al, 2004; except for Santiago. Note: the Santiago NMT mode share and trip rate range: the low end is for trips over 200 meters by people over five years of age (typical to traditional travel surveys; the high end is all trips in the public space made by all residents; additional detail in Chapter VIII).

That Santiago shares aspects of the various dimensions suggested in Table VI-1 may partly reflect its “middle income,” “dynamic growth” situation. It may even reflect the philosophical planning tensions – i.e., continental European and Anglo-Saxon – discussed in the following Chapter. On the one hand, one can look at Santiago relative to select industrialized cities (Table VI-2 and Figure VI-1) and see that, with the clear exception of the high density Asian cities of Singapore and Hong Kong, Santiago (as would be expected) exhibits lower rates of per capita automobile ownership and use, with per capita public transport patronage on the order of the Western European cities of Munich and Stockholm. Remarkably, except for the highly mobile North American and Australian cities, Santiago has a trip rate on par with the other cities.<sup>98</sup> In other words, while Santiago shows considerably lower mobility as measured by passenger kilometers traveled (PKT) per resident, *Santiaguinos* do not necessarily make fewer trips; looking at the relative density of the cities suggests that Santiago’s fairly compact form must be playing at least some role here.

<sup>97</sup> Throughout this Chapter, different measures of wealth will be used, in an effort to be consistent with the comparative purpose and comparison cases. When the analysis becomes Santiago-specific household income is almost universally used.

<sup>98</sup> Some of the variation in trip rate likely comes from differing trip definitions and survey responses; the cities with high auto usage may have higher trip rate in part due to definition issues (e.g. authorities primarily interested in motorized trips) or the recall issue (i.e., survey respondents more likely to recall motorized trips) or some combination. Finally, we cannot ignore potential data error in the Millenium Cities Database.

Turning to a selection of “developing” city peers – cities with roughly comparable GDP per capita (in the range of US\$5000-US\$9,000) – a wide-ranging picture emerges (see Table VI-3 and Figure VI-2). Except for the extremely low trip rate in Cape Town and, at the other end, the high rate in Prague, basic mobility measured in trips per capita across the cities appears similar, on the order of 2.1 to 2.8. The motorized two-wheeled Asian cities, Kuala Lumpur and Bangkok, show the important role that mode plays in personal motorized mobility, accounting for more PKT per capita than public transport in those cities. The cities show a range of densities, but outside of the Asian cities only Moscow exceeds Santiago’s density levels. Among these cities, Cape Town seems most akin to Santiago in basic urban structure (as grossly measured by density), motorization rate, and income. Notably, Cape Town seems to have higher combined PKT (combining public transport and auto), despite an apparent low trip rate. This could be a result of the legacy of apartheid and segregated urban development patterns (e.g., producing longer trip distances from townships).

**Table VI-3. Santiago. Basic Mobility Characteristics Relative to Select “Peer Developing” Cities**

Characteristics	Riyadh	Buda- pest	Prague	Moscow	Kuala Lumpur	Bangkok	Johan- nesburg	Cape Town	Santiago
Population (mns)	3.1	1.9	1.2	8.7	3.8	6.7	2.5	2.9	5.7
Metro GDP/capita (US\$1995)	5,939	5,679	9,145	5,103	6,991	6,316	5,137	4,243	5,500
Persons/Ha	44	51	49	146	58	139	30	71	80
Autos per 1000	221	299	442	149	209	249	269	143	145
MCs per 1000	0	7	48	7	175	205	6	8	3
Auto PKT per Person	7,807	3,122	4,346	3,057	4,345	2,991	4,927	3,136	1,450
MC PKT per person	2	19	22	20	1,365	1,411	49	94	46
Public Transport PKT per Person	107	3,627	4,321	7,153	726	2,799	3,277	1,521	2,450
NMT Mode Share	2	23	25	20	24	12	53	35	29-39
Daily Trips per Capita	2.2	2.5	4.6	2.7	2.7	2.6	2.1	1.4	2.4-2.8

Sources: Kenworthy and Laube, 2001; except for Santiago. Note: the Santiago NMT mode share and trip rate range: the low end is for trips over 200 meters by people over five years of age (typical to traditional travel surveys; the high end is all trips in the public space made by all residents; additional detail in the Chapter VIII).

Any conclusions from this gross data comparison should be made tentatively; beyond clear challenges to data comparability,<sup>99</sup> the lack of relevant cost/price information (e.g.,

<sup>99</sup> Information on the derivation of the indicators for the Millennium database is not readily available. The indicators may over-estimate PKT relative to Santiago if they are based on a simple extrapolation of work day. The Santiago numbers account for variation by time of year and weekday/weekend. Of course, the

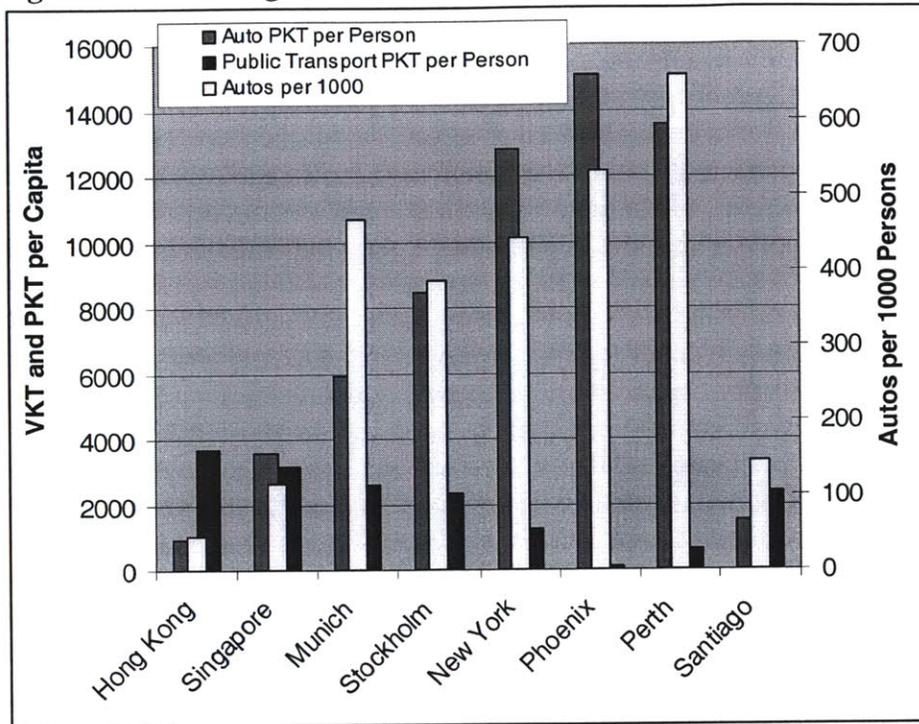
vehicle costs, fuel costs, transit fares) clearly represents an omitted factor of influence. Nonetheless, I dare make a few generalizations. First, clearly cities across the world exhibit a wide-range of travel outcomes, even when roughly controlling for income levels and motorization rates. Riyadh fulfills the expectation of high private vehicle use, attributable, no doubt to cheap fuel and the desert climate. In that sense, it seems on a path towards Phoenix. While the Asian developing cities clearly fulfill the stereotype of motorized two-wheeler “dependency,” wealthy Munich also shows a relatively high rate of usage of such vehicles. Prague, with a motorization rate on par with New York City, only generates a PKT per capita with those vehicles equivalent to residents of Kuala Lumpur.

What does this imply for Santiago currently and for the future? The city still finds itself in the early stages of motorization, but under rapid growth and development pressures. The data above seem to suggest Santiago has slightly lower motorization rates and private vehicle use relative to cities of similar income and structure. The World Bank (2002) shows Chile, nationally, with a motorization rate fairly low for its per capita income (measured at purchasing power parity) – considerably lower than Mexico, Argentina, Brazil and several Eastern European countries and actually falling, at the moment anyway, on Japan’s motorization trajectory. What direction might it take? If we look at the well-known Newman & Kenworthy curve associating urban passenger vehicle use to urban densities (see Figure VI-3, based on an update to the original Newman and Kenworthy data), then we can see that Santiago rests somewhere with the developing and wealthy Asian cities in terms of density and automobile use. Almost certainly it will move up the curve, but how far and at what rate? Before looking to explore that question in more detail, let’s first examine more closely the city in the Latin American context.

---

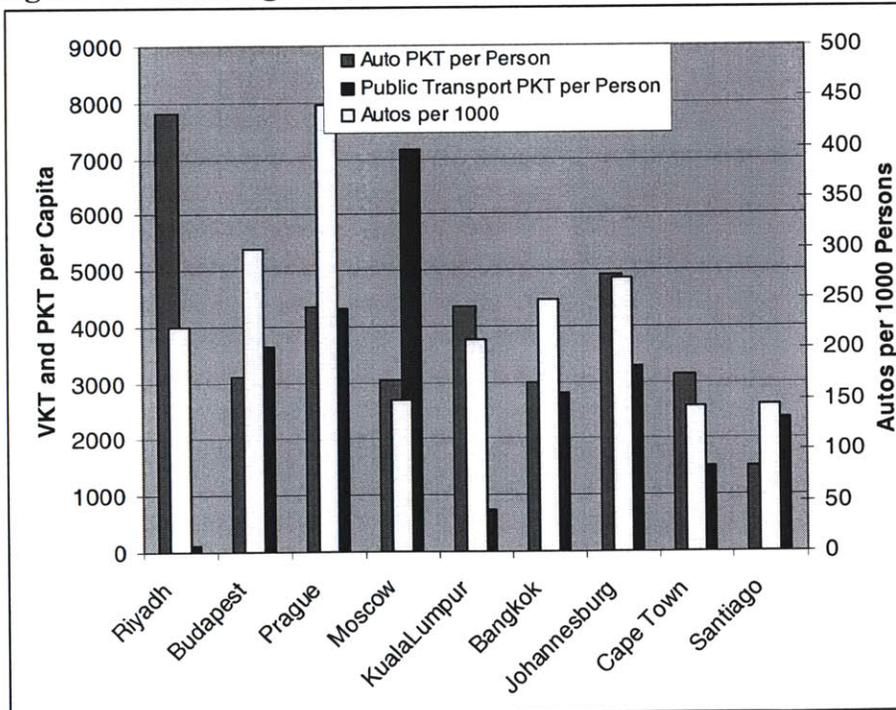
Santiago numbers may be underestimated and are not immune to possible error, including due to errors in coding trip origins and destinations, distortions due to the use expansion factors, and errors in data-processing.

**Figure VI-1. Santiago Relative to Select Industrialized Cities**

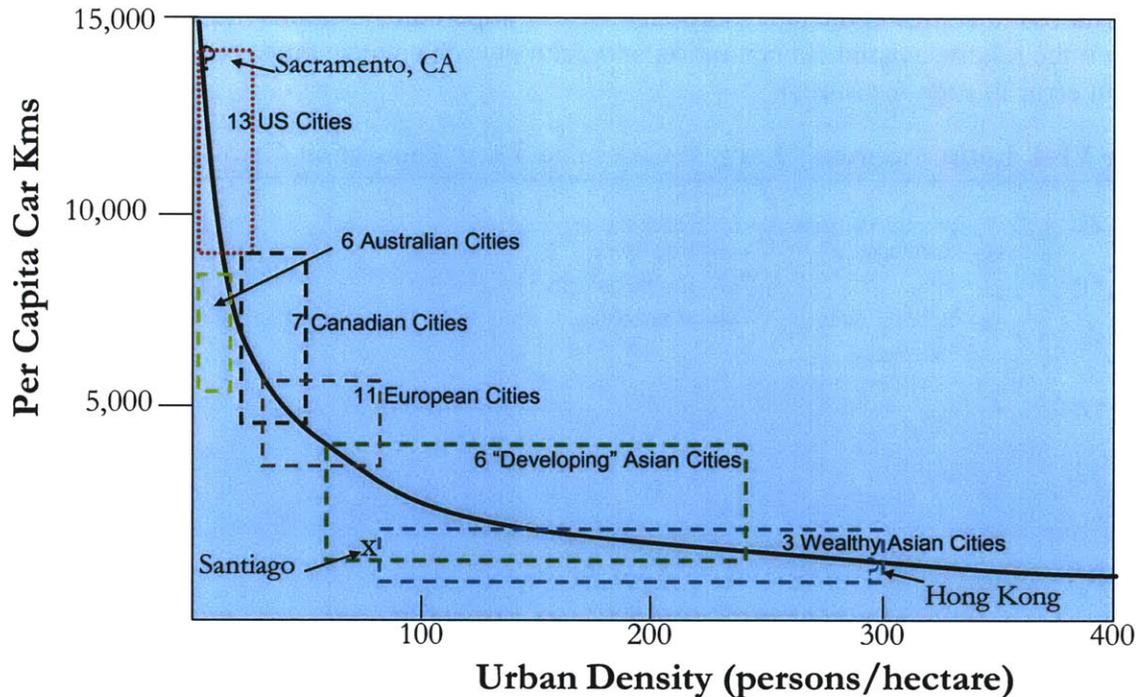


Sources (above & below): Derived from Kenworthy and Laube, 2001; Except Santiago.

**Figure VI-2. Santiago Relative to Cities in Similar Income Range**



**Figure VI-3. Private Vehicle Use & Density: A Global Comparison (1990)**



Sources: Kenworthy & Laube, 1999; Santiago for 2001, from various sources (see following Chapters).

### VI.1.1 Regionally

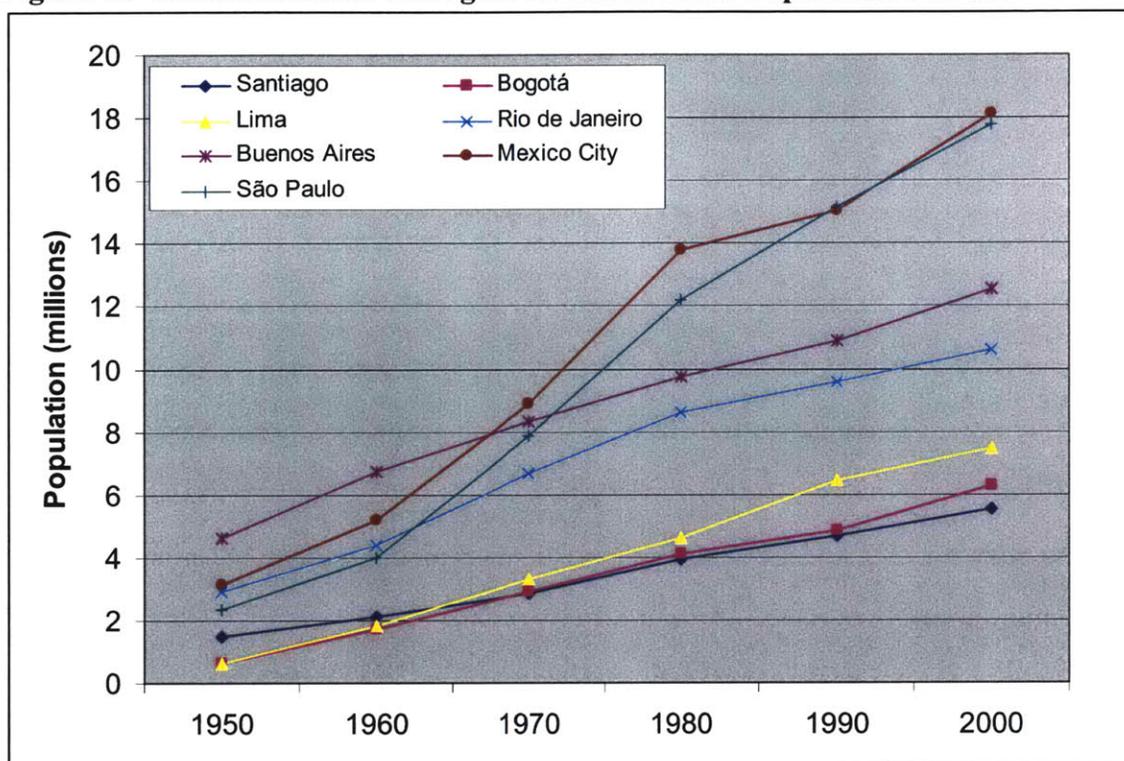
Of the seven Latin American cities with more than 5 million persons (as of 2001), Santiago has exhibited fairly moderate growth rates over the past half Century (Figure VI-4).<sup>100</sup> Notably, Santiago, along with Lima and Buenos Aires and to a lesser degree Mexico City, epitomize the primate city phenomenon, accounting for 43%, 40%, 38% and 25%, respectively, of their nations' urban populations (see Table VI-4). Both Colombia and Brazil (as well as Ecuador and Venezuela) are characterized by a more dispersed national pattern of cities; as such, cities like São Paulo and Rio de Janeiro, despite their massive size, comprise a small share of Brazil's total urban population. Looking at Table VI-4, one can see that Chile, Argentina and Mexico are now characterized by the UNDP as having achieved a "high" development category (as measured by the Human Development Index). Note, however, that Chile, together with the other Latin American countries listed, still displays very high income inequality as measured by the Gini Coefficient (see Table VI-4).<sup>101</sup> Based on purchasing power parity-adjusted GDP per capita, Argentina is still the wealthiest of the respective nations (US\$11,300) (despite the sharp economic downturn experienced since the early 2000s),

<sup>100</sup> Note, virtually all of these cities were among the largest of the Spanish colonial cities, with populations at the end of the 18<sup>th</sup> Century: Buenos Aires, 38,000; Santiago, 30,000; Lima 53,000; Bogotá, 18,000; Mexico City, 130,000; Rio, 53,000; Sao Paulo 25,000 (1819) (Borah, 1980). The other large cities of the time, Caracas and Havana would experience slower relative population growth rates in the 20<sup>th</sup> Century.

<sup>101</sup> The Gini index measures inequality over the entire distribution of income, with a value of 0 representing perfect equality and a value of 100 perfect inequality.

followed by Chile (\$9,200) Mexico (\$8,400), Brazil (\$7,400), Colombia (\$7,000) and Peru (\$4,600). We can expect this relative wealth to be a fair proxy for comparing the wealth across the cities in the table, although clearly important variations might exist based on the relative spatial concentration of wealth in each country (and recognizing the inherent error in such measures).<sup>102</sup>

**Figure VI-4. Latin America's Largest Cities and Their Population Growth**



Sources: Villa and Rodríguez, 1996; UN-HABITAT, 2001.

Bogotá and Lima continue to mark fairly high population growth rates (over 2%, projected to at least 2005), this may be a reflection of the still lower economic prospects in the nations' country-sides and, in the case of Bogotá, ongoing civil strife making cities fairly attractive "safe havens." From a transportation perspective, the cities (for which data are available) show fairly consistent *motorized* trip rates; on the order of 1.3 trips per person per day. At least two interesting observations can be gleaned from the trip rate information. One is the apparent declining trip rate evident in São Paulo (from 1987-1997), which may be do to data inconsistencies (although the same agency has been responsible for data collection for each of São Paulo's four travel surveys), but may also reflect travelers' responses to increased congestion, a re-arrangement of trip making behavior (increased trip-chaining), a change in socio-economic and demographic characteristics, a response to public safety concerns, and/or a combination of these

<sup>102</sup> Note that these values differ from those derived from Kenworthy and Laube (2001), presented in the previous section. This is for the purpose of consistency; all else equal, purchasing power parity-adjusted GDP is a preferable means of showing relative wealth across countries.

factors.<sup>103</sup> The second observation stands in direct contrast to the first: Santiago's growing *motorized* trip rate, reaching 1.75 trips per person per workday, which is almost the same as São Paulo's total trip generation rate.<sup>104</sup> These differences have interesting possible implications for the region; will other cities in the region follow the Santiago path (apparently consistent with increased income in most other countries, such as the industrialized world average trip rates of 3-4 trips per person per day; e.g., Schafer, 2000); or does the Latin American mega-city (and some of its unique characteristics) have something else in store?

In terms of travel modes, the gross comparison in Table VI-4 shows a still heavy mode share for walking trips, at least partly reflective of still not insignificant shares of very poor populations in these cities. And, again despite the inherent difficulties in ensuring accuracy and comparability across the data, the most recent travel surveys indicate a growing private vehicle mode share, exceeding the share of bus trips in São Paulo, and rapidly approaching that situation in Santiago. Santiago, despite the opening of a new Metro line in 2000, has actually experienced a slight decline in Metro mode share; while São Paulo's has, apparently, remained constant. Mexico City's declining Metro mode share has been notorious – reportedly declining from 23% of trips in 1983 to 14% in 1995 (COMETRAVI, 1999).<sup>105</sup>

---

<sup>103</sup> Note, the total trip rate (i.e., including non-motorized trips) also declined from 2.06 to 1.87 during the same period. See an interesting exploration of some of these issues in Strambi and van de Bilt, 2003.

<sup>104</sup> Note that in this table, for comparative purposes, the Santiago information is only for trips greater than 200 meters and by people over 5 years old. These data differ from those analyzed in the following Chapter (when generally, all trips by all persons are analyzed); but I believe that presenting the Santiago data in this form is likely more comparable to the other city information (although no additional detail on the other cities' travel survey target population was available). In any case, ensuring full comparative consistency across the surveys is nearly impossible.

<sup>105</sup> Both Santiago and São Paulo recorded increases in total daily Metro trips: an 18% increase (from 1.4 to 1.7 million trips/day) in the 10 years between 1987-1997 in São Paulo; and a 28% increase (from 0.5 to .643 million trips/day; including all transfers) in the 10 years between 1991-2001 in Santiago. Mexico City, on the other hand, actually experienced a decline in total recorded ridership (which may not necessarily be the same as trips made due to, e.g., fare evasion, etc.) – from 4.2 million in 1989 to 3.5 million in 1999 (São Paulo and Santiago data from sources in Table VI-4; Mexico from INEGI, 1999).

**Table VI-4. Santiago and Her *Hermanas Latinas*: The Large Latin American Cities**

City (Year for Mode Share Data)	Walk Share All Trips	Mode Share for Motorized Travel (Work Day)				Motor Veh. Trip Rate	Pop. (2000) (mns)	City Share of Nation Urban Pop.	Annual Pop. Growth Rates		Basic Socioeconomics (National Data)					
		Auto	Bus	Metro/ Train	Taxi				1985- 1995	1995- 2005	GDP Growth Rate	GDP/ Cap (\$2001)	Life Exp.	HDI (rank)	Gini- Coef.	HD Cat.
Santiago (2001)	27	38	42	7	6	1.75 (2001)	5.6	43%	1.9	1.7	2.3	9,190	76.3	0.831 (43)	57.1	High
<i>Santiago</i> (1991)	21	19	61	9	4	1.29 (1991)	4.5 (1991)	<i>n.i.</i>	<i>n.i.</i>	<i>n.i.</i>	<i>n.i.</i>	<i>n.i.</i>	<i>n.i.</i>	<i>n.i.</i>	<i>n.i.</i>	<i>n.i.</i>
Bogotá (~2000)	23	20	80	n.a.	n.i.	n.i.	6.3 (2000)	20%	2.5	2.1	1.2	7,040	71.8	0.779 (64)	57.6	Med.
Lima (2004)	25	11	69	n.a.	6	1.5	7.4 (2000)	40%	2.7	2.1	2.5	4,570	69.8	0.752 (82)	49.8	Med.
Rio de Janeiro (1980s)	n.i.	24	64	11	n.i.	n.i.	10.6 (2000)	8%	1	0.8	1.6	7,360	68.6	0.777 (65)	59.1	Med.
Buenos Aires (1991)	n.i.	14	50	10	n.i.	1.26 (1992)	12.6 (2000)	38%	1.2	1.1	-2.1	11,320	74.3	0.849 (34)	52.2	High
São Paulo (1997)	34	47	38	11	n.i.	1.21 (1997)	17.8	13%	1.8	1.3	1.6	7,360	68.6	0.777 (65)	59.1	Med.
<i>São Paulo</i> (1987)	36	43	43	11	<i>n.i.</i>	1.32 (1987)	<i>n.i.</i>	<i>n.i.</i>	<i>n.i.</i>	<i>n.i.</i>	<i>n.i.</i>	<i>n.i.</i>	<i>n.i.</i>	<i>n.i.</i>	<i>n.i.</i>	<i>n.i.</i>
Mexico City (1995)	8	22	55	14	9	1.29 (1994)	18.1	25%	1.4	1.1	2.4	8,430	73.5	0.800 (55)	54.6	High

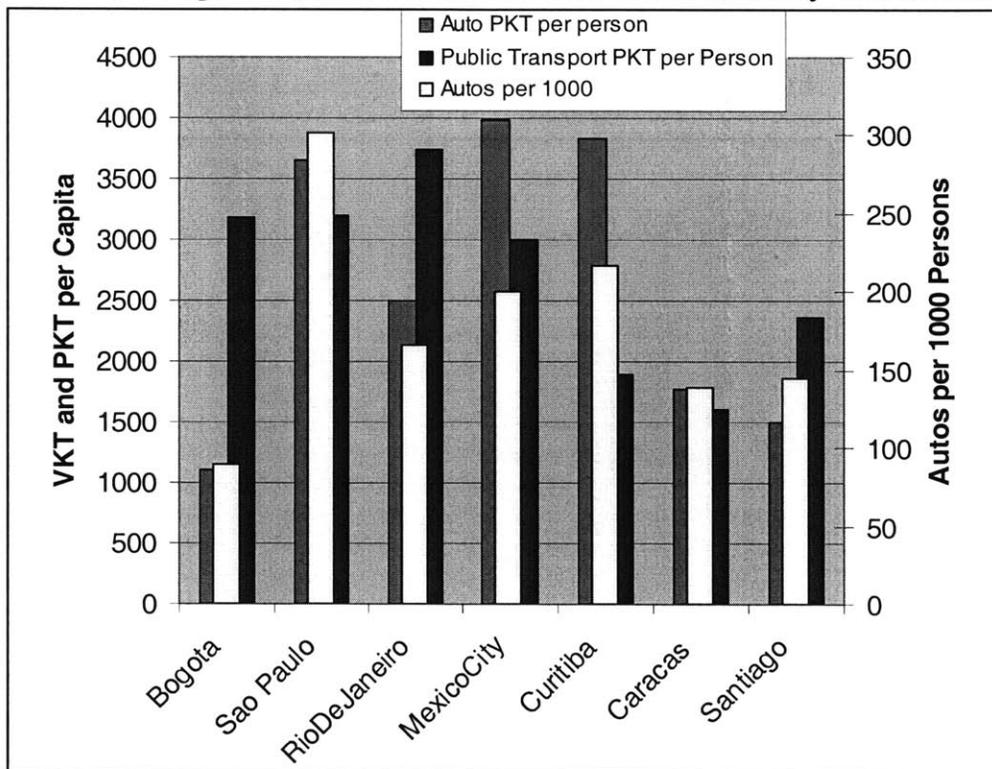
Sources: COMETRAVI, 1999; Companhia do Metropolitano de São Paulo, 1999; JICA, 2004; Kenworthy & Laube, 2001; SECTRA, 2004; STT, 2005; Thomson, 2002; UN-HABITAT, 2001; UNDP, 2001; UNDP, 2004; Vasconcellos, 1995; World Bank, 2005. Notes: The cities are listed in ascending order, based on 2000 population. Keep in mind the difficulty in comparing such data, due to differences in definitions of trip types (including target population, trip length), differences in definitions of metropolitan areas, other differences in techniques, etc. which can lead to variation in results. GDP/Capita measured at Purchasing Power Parity (PPP); GDP Growth Rate is the average of annual growth rates from 1999-2003; Life Expectancy is for 2002. HDI = Human Development Index, 2001. HD Cat.= Human Development Category. Years for Gini Coefficient: Argentina, 2001 (*note, Argentine value only for urban areas, likely underestimating national value*); Brazil, 1998; Chile, 2000; Colombia, 1999; Mexico, 2000; Perú, 2000. n.i.- no information; n.a.-not applicable.

**Table VI-5. Santiago and Select Latin American Cities: Mobility Characteristics**

Characteristics	Bogota	São Paulo	Rio de Janeiro	Mexico City	Curitiba	Caracas	Santiago
Population	5.6	16.6	10.2	15.8	2.4	4.6	5.7
Metro GDP (US\$1995)	2,959	5,319	8,727	3,575	6,515	n.a.	5,000
Persons/Hectare	116	78	58	107	30	163	80
Autos per 1000	89	301	166	200	216	139	145
MCs per 1000	6	21	8	3	16	17	3
Auto PKT per person	1,102	3,650	2,507	3,988	3,833	1,767	1,450
MC PKT per person	18	130	45	9	165	111	46
Public Transport PKT per Person	3,176	3,196	3,743	3,003	1,890	1,607	2,450
NMT Mode Share	23	35	22	8	34	n.a.	29-39
Daily Trips per Capita	1.6	1.9	1.2	2.1	2.1	n.a.	

Sources (Table above and Figure Below): Kenworthy and Laube, 2001; except Santiago

**Figure VI-5. Santiago and Select Latin American Cities: Mobility Characteristics**



The Millennium Cities Database (MCD) offers an alternative take on some of the same Latin American cities; the comparison serves two purposes. First, it helps show some of the challenges in making international comparisons – and, thus, the caution that should be used in drawing major conclusions from them.<sup>106</sup> Second, however, it provides insights

<sup>106</sup> The MCD seems fairly accurate in its limited data on Santiago; some of the data (e.g., trip rate, motorization rate) are slightly below those figures reported in the 1991 OD Survey (SECTRA, 1992a); the mode share data does not match that reported for the 1991 survey, but seems to be based on some

from additional cities, most notably the famed Latin America transport paragon, Curitiba, Brasil. Well-known for its efficient, bus priority-based public transport system and integrated land use-transport development approach, the city stands out in this comparison for its relatively low density (lowest among the cities shown) and its high automobile usage – second only to Mexico City (see Figure VI-5).

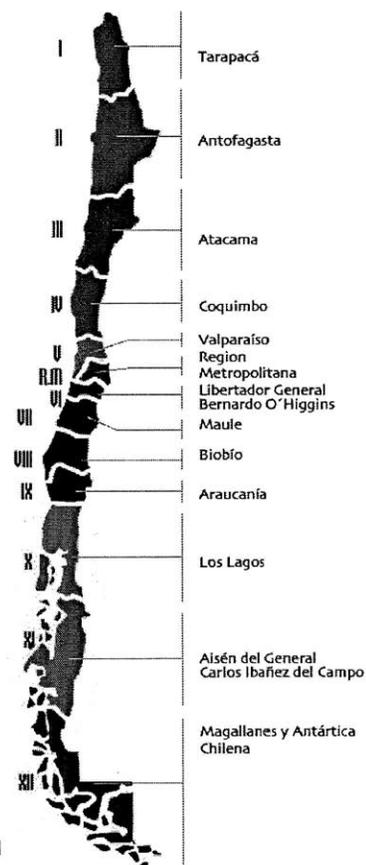
### VI.1.2 Santiago in the National Setting

Finally, and “closest to home,” we need to situate Santiago within the national setting. Chilean authorities estimate national income per capita at US\$4,620 per year (MIDEPLAN, 2005). Santiago’s per capita income is likely slightly higher than that, given its high concentration of the nation’s wealth and low share of households classified as living under the poverty line (10.8% in the Metropolitan Region, see Table VI-6). Officially, the estimated cost of a basic urban basket of goods (i.e., subsistence) in the country is US\$36 per person per month. The official minimum monthly wage is approximately US\$200 per month, or \$2,400 per year (MIDEPLAN, 2005).

**Table VI-6. Percentage of Chilean Households Living in Poverty, By Region**

Region	Indigent	Non-Indigent	All Poor
I. Tarapacá	2.6%	12.4%	15.0%
II. Antofagasta	2.8%	7.0%	9.8%
III. Atacama	5.8%	13.8%	19.5%
IV. Coquimbo	4.5%	13.5%	18.0%
V. Valparaíso	3.9%	11.7%	15.6%
RM. Metropolitana	2.5%	8.3%	10.8%
VI. O’Higgins	3.3%	11.9%	15.2%
VII. Maule	4.8%	15.0%	19.7%
VIII. Bio Bio	6.9%	16.2%	23.1%
IX. Araucanía	7.1%	16.9%	24.1%
X. Los Lagos	4.0%	14.1%	18.2%
XI. Aysén	4.2%	8.0%	12.2%
XII. Magallanes	1.8%	6.3%	8.1%

Source: MIDEPLAN, 2003.



**Figure VI-6. Map of Chile’s Regions (right)<sup>107</sup>**

Despite impressive economic growth over the past 15 years, poverty, including in the cities, which concentrate nearly 90% of Chile’s population today. Table VI-7 shows the 16 principal cities of Chile, ranked ascending by population; these cities account for roughly 65% of the nation’s population. Again, the primacy of

extrapolation from that survey. The data on passenger car use per capita (1,215 PKT/Capita) and public transport use per capita (2,776 PKT/Capita) are roughly in line with the data I have derived, particularly given likely evolution in modal usage since 1995 (ostensibly the base year for the MCD).

<sup>107</sup> The map comes from [http://www.vi-e.cl/internas/aprende/lo\\_mejor/regiones/indice.htm](http://www.vi-e.cl/internas/aprende/lo_mejor/regiones/indice.htm).

Santiago stands out; the next two largest cities (both ports), Valparaiso (Chile's historical commercial port) and Concepción (Chile's military port) are just 15% the size of Santiago.

Recent travel surveys carried out under the auspices of national authorities (SECTRA) in the past decade allow an interesting glimpse into the similarities and differences in these cities (see Table VI-7 and Figure VI-7) in terms of basic travel characteristics.<sup>108</sup> A general trip rate of 2 trips per person per day is fairly consistent across the cities; the primary exceptions are Valparaiso, Concepción, Temuco and Chillán, each of which had unemployment rates of 10% or higher at the time of the survey. Punta Arenas also exhibits a lower trip rate, despite low unemployment; but Punta Arenas also has the highest concentration of retirees (10%) among the cities for which that information was available. Against these cities, Santiago's trip rate stands out as the highest among the cities; perhaps due to higher income, but also perhaps due to the big city "hustle and bustle." Somewhat interestingly, most likely the wealthiest city in the group, Antofagasta (home to large mining operations), does not have a remarkably high trip rate.

Turning to mode share and auto ownership across the cities, the evidence shows a heavy dependence on walking as the basic mode of transport, accounting for 20% to 40% of daily work day trips. No apparent pattern relating walking to city size clearly emerges. Shared taxis (*colectivos*) play an important role as well, especially but not exclusively in the smaller cities. As such, a general trend appears in which bus transport mode share increases with city size. As we would expect, an apparent relationship between auto ownership<sup>109</sup> and auto mode share exists. Notably, the cities with duty free trade zones (Iquique, Punta Arenas and Arica<sup>110</sup>) have the lowest share of "auto-less" households in the nation; clearly households have taken advantage of the free importation of used vehicles allowed in these. Punta Arenas has the highest auto mode share, followed by Santiago, and then Iquique. Finally, the data indicate some predilection for bike travel, not only in Curico (Chile's most bicycle-friendly city), but in other cities further South (notorious for rainy winters), such as Talca and Chillán – in these cities bicycle mode share ranges from 7 to 11% of work day travel.

---

<sup>108</sup> We can, in general, have more faith in the comparative consistency across these survey results as opposed to those reported across different nations in the previous Sections VI.1 and VI.1.1.

<sup>109</sup> As measured by percentage of households with no motor vehicle in the home, the only relevant data point that was universally available across the surveys.

<sup>110</sup> The duty free zone exists at the Port of Iquique, however the zone benefits extends to the city of Arica and other areas of Chile's northern Region I.

**Table VI-7. Chile's Principal Cities, Demographics, Socioeconomics**

City	Year	Trip Rate	Demographics (thousands)		Pers/HH	Percent Poor (Region)	Unemployed	Percent HHs in Income Category		Education Level	
			Pop.	HHs				Low	High	Univ.	High School
Curico	1996	2.06	65.6	17.9	3.67	20%	3.0%	65%	4%	6%	40%
Copiapo	1998	2.1	111.6	27.9	4	20%	n.a.	n.a.	n.a.	n.a.	n.a.
Punta Arenas	1998-9	1.84	112.5	31.9	3.53	8%	3.0%	39%	7%	9%	33%
Valdivia	1996	2.15	122.1	29.6	4.13	18%	11.0%	53%	10%	13%	38%
Puerto Montt	1998	1.94	125.5	32.2	3.89	18%	4.0%	45%	10%	9%	31%
Talca	1996	2.15	153.8	41.2	3.73	20%	4.0%	63%	6%	10%	38%
Chillan	1996	1.50	168.2	38.7	4.35	23%	12.0%	65%	5%	9%	40%
Arica	1998	2.12	171.0	42.4	4	15%	4.4%	48%	5%	9%	34%
Iquique	1998	2.17	185.4	45.9	3.9	15%	3.5%	31%	9%	9%	36%
Temuco	1996	1.85	231.0	57.6	4.01	24%	11.0%	34%	6%	13%	43%
Rancagua	2000	2.05	243.5	61.0	4.00	15%	4.2%	37%	14%	11%	33%
Antofagasta	1998	2.09	248.7	60.3	4.1	9%	3.0%	26%	18%	12%	33%
Coquimbo-La Serena	1999	2.05	259.9	63.8	4.1	18%	5.9%	49%	3%	8%	36%
Concepcion	1999	1.86	834.0	200.7	4.16	23%	13.0%	52%	7%	8%	39%
Valparaiso-Viña del Mar	1999	1.47	858.5	224.4	3.83	16%	10.0%	31%	9%	12%	38%
Santiago	1991	1.69	4,502.1	1,162.8	3.87	n.a.	3%	49%	9%	9%	34%
Santiago	2001	2.39	5,772.6	1,473.7	3.92	11%		40%	6%	13%	35%

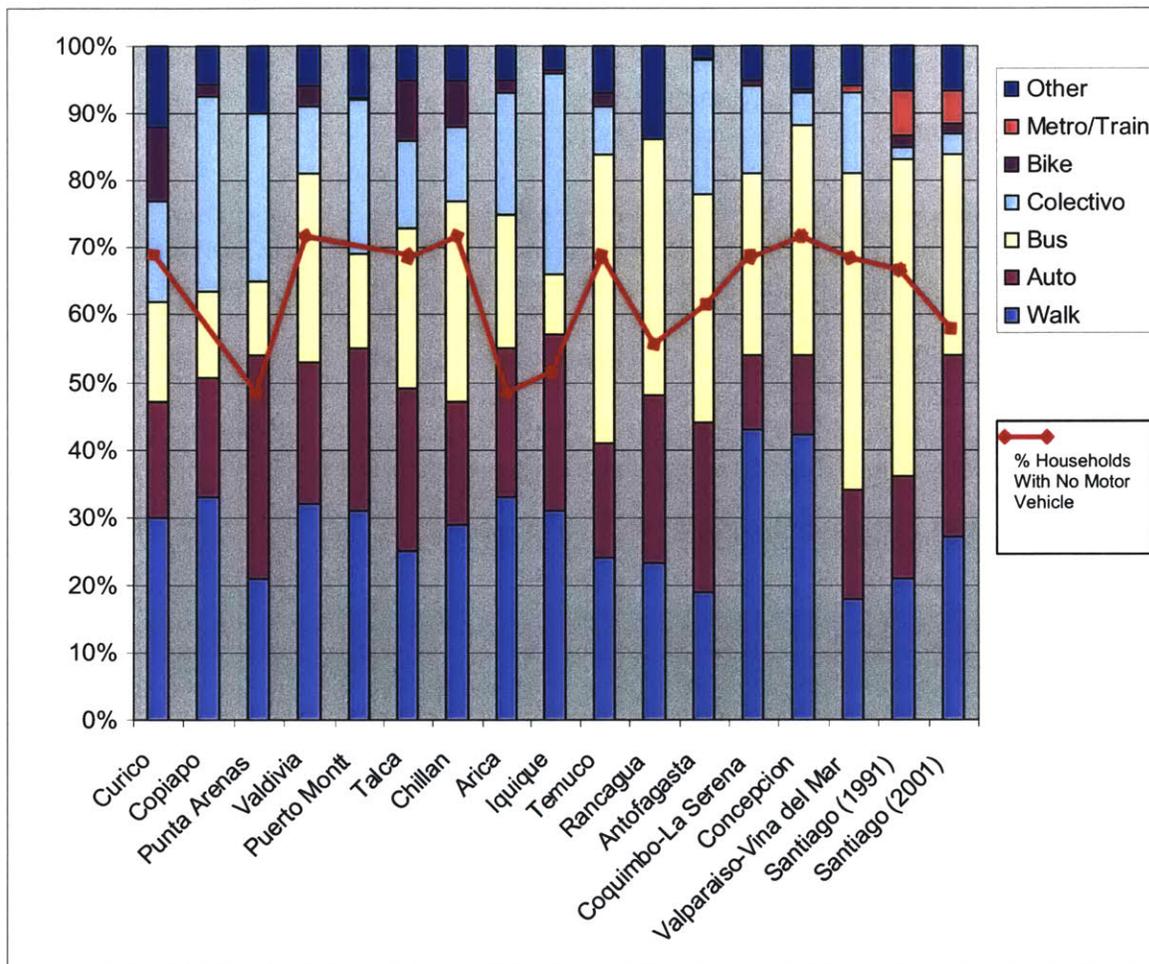
Sources: Derived from reports on the origin-destination surveys for each city (SECTRA, 2005) Santiago comes from SECTRA, 1992b, 2004. Note: In Curico, Talca, Chillan, secondary education is combined with Technical/Professional Degree; the ranges of household incomes encompassing the two income categories reported here (middle income is not included for parsimony) are not entirely consistent across each city. Roughly, the range is (in US\$2001 per year): 0-\$4,000 per year, low; \$4,000-15,000, medium; over \$15,000, high. Both high school and university may include individuals still studying. The 2001 data for Santiago have been made comparable with these surveys by only including trips >200 meters by persons > 5 years old.

## VI.2 Conclusion

From this Chapter's attempt to situate Santiago in the international, regional, and national contexts, several noteworthy characteristics emerge. First, structurally, Santiago exhibits high gross metropolitan-wide population densities, on the high end of European city densities and low end of industrialized Asian city densities, or, in a historical context, roughly comparable to Chicago circa 1960. In terms of basic travel patterns, Santiago apparently has a trip rate largely on par with industrialized cities and somewhat higher than other large cities in Latin America. At the same time, Santiago seems to have a lower motorization rate and a still higher share of public transport use (measured by passenger distances traveled) relative to several of her large sister cities in the region. It is not entirely clear whether this lower motorization derives from different

tastes/lifestyles, vehicle prices and operating costs, urban structure and form, income distribution (although Chile does not have a considerably different Gini-coefficient than other countries in the region), and/or other relevant factors. Notably, relative to Mexico City, Santiago has been able to at least maintain Metro ridership levels, although Metro's overall mode share has been declining. Relative to other Chilean cities, the capital has higher trip rates – perhaps a reflection of large city hustle and bustle – but does not have the highest household motorization levels.

**Figure VI-7. Mode Share (Work Day) and Share of Households with No Motor Vehicle: Primary Chilean Cities**



Sources: Same as in Table VI-7. The relevant year for each city can also be found in Table VI-7. In Valdivia, Bicycle includes Motorcycle; for Rancagua, Public Transport mode was not disaggregated. The cities are listed in ascending order, based on population size, from left to right. Household auto ownership information was not available for Copiapo or Puerto Montt.

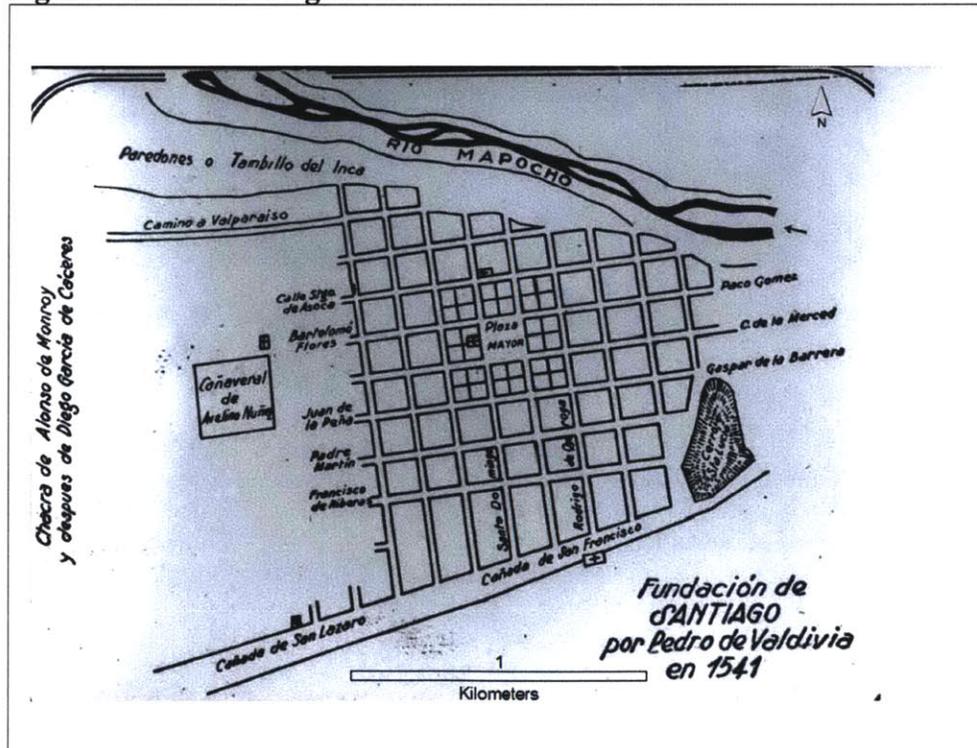
## VII EXPLORING A METROPOLIS: PLANNING, PEOPLE, FORMS AND DESIGNS

This Chapter introduces the physical side of Santiago de Chile, starting first with brief overview of planning traditions and influences. The socio-spatial characteristics of the city are then presented, focusing on general trends in population growth, household income growth, and indicators of spatial segregation. Then, Santiago's built environment is detailed, including at metropolitan-scale structure, meso-scale form, and micro-scale design characteristics. Finally, a typology of Santiago's hypothesized neighborhoods is presented, together with results from multivariate analyses attempting to confirm those typologies based on built environment characteristics alone.

### VII.1 Santiago de la Nueva Extremadura

One summer day, in 1541, Pedro de Valdivia, arriving south from Perú, camped with his men at the foot of a hill in the broad Mapocho river valley of the land known as Chile. Aiming to expand the Spanish territories to the South and, as always, in search of gold to please the motherland, de Valdivia and his men decided to found a city near Huelén hill (which he would christen *Cerro Santa Lucia*). Following the colonial rules of the day, de Valdivia had his *alarife* (akin to a Director of Public Works), Pedro de Gamboa, lay out the grid for the city to be called *Santiago de la Nueva Extremadura*.

Figure VII-1. The Original Grid and Plaza de Armas



Note: Scale is approximate. Source: Biblioteca Nacional, Archivo Fotográfico y Digital, Santiago de Chile.

A detailed history of the development patterns and forces shaping Santiago clearly extends beyond the scope of this dissertation. Nonetheless, a brief overview of major relevant forces influencing Santiago provides a useful backdrop to this research. Cavric et al (2004) suggest that Chile's history can be broadly categorized into four periods: "Mercantilist," "Outward Growth," "Liberal Model," and "Transnational Capital" (see Table VII-1). These periods, as suggested in Table VII-1, can be associated, generally, with trends in relevant urban planning, economic, social and transportation spheres. Santiago, structurally, developed primarily by propagation of the colonial grid, even more so than her regional kin (e.g., Buenos Aires and Rio de Janeiro, where grand diagonal boulevards appeared), despite numerous proposals for diagonal road development (in the Haussmann tradition) (Hofer, 2003).

Through the 1870s, Santiago's urban development processes were dominated by large transactions between the state and landed aristocrats, important public works projects (e.g., bridges across the Mapocho, inter-city rail lines and urban tram lines), and large state buildings such as the National Library and the Congress. Beginning in the 1870s, buoyed by resources from the boom in nitrate mining, and following the first formalized planning efforts (e.g., building height regulations) of the Mayor Vicuña Mackenna, various structural proposals were put forward (e.g., 1894, 1908, 1912, 1913; see Hardoy & Langdon, 1980; de Ramón & Larraín, 1980; Hofer, 2003), with a particular focus on introducing diagonal avenues in the face of the predominance of the colonial grid. Except for some of the projects in the Vicuña Mackenna plan (such as channeling the Mapocho River, developing certain radial avenues, creating the Santa Lucia Park), few other major plan proposals would be realized (Figueroa, 1996; Hofer, 2003).

By the early 20<sup>th</sup> Century, with the city facing increasing quality of life pressures due to industrialization, in-migration, and crowding, "modern" planning practices emerge (see, also, the discussion in Section II.3.1). Naturally, this also marks the birth of development concepts which would become known as "modernization theory" – breaking with the traditional; developing through interdependent political, social and economic change; enhancing exchange with "modern" societies. In Santiago during this time, modern planning ideas could be seen in the emergence of modernist office buildings in the central business district (CBD) and "garden city"-inspired suburbs in the East and South (Aguirre and Castillo, 2004). At the same time, planning and policies continued with an apparent disregard for the harsh realities underlying Santiago's development pressures: extremely crowded living conditions for the poor and increasing demands for additional space due to demographic growth (Hofer, 2003). The late 1920s witnessed the emergence of more formal urban planning<sup>111</sup> in Chile, most notably: the first University-level urban planning course (in the University of Chile) in 1928 (Hofer, 2003); the promulgation of the nation's first national legislation on urban development in 1929; and, in that same year, the arrival of the Austrian urban planner, Karl Brunner, for a two year stint in Chile.

Brunner first came to Chile to work as an advisor to the Ministry of Public Works. A Chilean contemporary credits Brunner with bringing "scientific-functionalist" urban

---

<sup>111</sup> In Chile, the word most commonly used for urban planning is *urbanismo*, a word which, according to Aguirre & Castillo (2004), only came into widespread use after 1929.

planning to the country (Muñoz, 1937, cited in Hofer, 2003). Brunner appears to have carried out the first formal survey of the city's low income settlements (at the time called *conventillos*) (Hofer, 2003).<sup>112</sup> In his work detailing Brunner's influence in Latin American urban planning, Hofer (2003) notes several relevant characteristics of Brunner's approach to, and beliefs about, urban planning, as they related to Santiago at the time, such as the need to: be sensitive to, and fully considerate of, local conditions and realities; reduce the city's mono-centricity; plan for the entire conurbation (anticipating urban expansion); develop mixed-use zones and industrial zones; and, create residential areas (Brunner was influenced by the "garden city" movement). Brunner proposed a metropolitan plan for the Santiago area, developed several urban development plans for Municipalities in Santiago, lobbied for the development of an integrated urban development plan for Greater Santiago (an effort that would not be realized until 30 years later), and also taught the *urbanismo* course at the University of Chile (Aguirre and Castillo, 2004; Figueroa, 1996; Hofer, 2003). Through these activities, Brunner would have a lasting influence on urban planning theory and practice in Chile (see, e.g., *Revista de Arquitectura*, 1996).

### VII.1.1 Modern Planning Tensions

If Brunner marks the point of the arrival of "modern" planning practices to Chile (e.g., Aguirre and Castillo, 2004), he stands in some contrast to the high "modernists," embodied in the principles of the "Charter of Athens" and epitomized, to the extreme, by the ideas of Le Corbusier (see Section II.3.1). By Hofer's (2003) account, the contrast between Brunner and Le Corbusier rested in Brunner's sensibleness towards local conditions and his rejection of the modernist *tabula rasa* approach and associated beliefs in meta-theories and designs. Despite Brunner's lasting influence in Chile, more purely modernist influences would inevitably enter urban planning practices in Chile.<sup>113</sup> In fact, Sabatini and Soler (1995) suggest that the 1960 Intercomunal Plan for Santiago was strongly influenced by the "Charter of Athens," particularly the four vital urban functions (housing, work, recreation and circulation). Sabatini and Soler suggest that 1960 Plan, indeed even earlier plans for Santiago, reflected an ongoing philosophical tension between the continental European compact city – characterized by higher densities, medium height buildings and continuous façades – and Anglo-Saxon town planning epitomized by the "garden city."<sup>114</sup> Garden city-type expansion, central business district predominance, and radial commercial corridors largely prevailed.

The 1960s were marked by political upheaval and ongoing social pressures due to continued income inequalities and challenges to housing ever-increasing numbers of

---

<sup>112</sup> Estimates range on the number of *Santiagoños* living in *conventillos* or other marginal settlements at the time. Matas & Balbontin (1987) estimate that in 1910, 18% of Santiago's population lived in precarious housing conditions; according to Hofer (2003), Brunner estimated nearly 40% of the city's population lived in *conventillos* by the 1930s.

<sup>113</sup> Hofer (2003) notes that at least one offer by Le Corbusier, who developed several planning proposals for other Latin American cities (e.g., Buenos Aires, Rio de Janeiro), to come to Chile was rejected by the Chilean government.

<sup>114</sup> As mentioned, Brunner was influenced by the "garden city" movement and his plan indicated a favorable view of the garden city in extension which had already begun by middle and upper classes (Sabatini and Soler, 1995).

poor. The authoritarianism of the 1970s brought large efforts to dislodge the poor and relocate them on the periphery and the accompanying neo-liberal economic ideas showed a general disdain for urban planning. In 1979, the government lifted the urban growth boundary from the 1960 plan. The military regime did, nonetheless, exhibit a fairly restrained approach to large urban transportation infrastructure development (the Metro aside) and a transport “demand management” (in no small measure influenced by the universities) mentality largely reigned (for more details, see Zegras & Gakenheimer, 2000). A few years after the return to democracy came another metropolitan (Intercomunal) regulatory plan, approved by authorities in 1994.

In recent years, multiple, often inter-related factors have contributed to Santiago’s urban growth patterns (again, see Zegras & Gakenheimer, 2000). Income growth, bringing concurrent motorization and demand for residential space, continues to strengthen suburbanization pressures. Real estate company growth and land speculation reinforce the pressures, producing large scale office, residential and industrial projects. Lower-income housing demand, typically satisfied on the lower-priced urban fringe, further fuels expansion. From a public policy perspective, a number of initiatives have produced somewhat countervailing effects. Increasing investments in transportation infrastructure – in part through the national government’s highway concession program - play a clear role, opening access to previously undeveloped land. On the other hand, an urban renovation subsidy program created incentives for the development of some 22,000 new apartments in the central city since 1992 (IEUT, 2004). Further fueling outgrowth, however, a 1997 modification to the Intercomunal land use plan, largely in response to pressures from real estate developers and large-scale land speculators, opened up almost 20,000 hectares for urban development on the rapidly expanding northern urban fringe. As part of the plan modification, authorities introduced conditional development zones, aimed at inducing “self-sufficient” real estate projects<sup>115</sup>. Authorities have also employed, in a somewhat ad-hoc approach, impact fees in the area in an attempt to charge developers for the necessary trunk road infrastructure and even some degree of transport air pollution resulting from this fringe development (see details in Zegras, 2003). Most recently, the government, with some international agency support, has been exploring “location efficiency” concepts (see related analysis in Browne et al. 2005).

In sum, Santiago continues to manifest important aspects of its colonial legacy, including through a still heavy mono-centricity and prevalence of the grid-street network, although a fully modern city has now emerged. In terms of land development activities, public and private actors each still play an important role. The public sector acts through direct subsidies for lower income housing and indirectly via subsidies to the construction industry, plan modifications and infrastructure investments. Private sector activity has grown from fairly small-scale activity in urban edge subdivisions into massive real estate megaprojects fully perpetuating the garden city. On the other side, small scale, self-construction settlements continue, primarily by the poor (Greene and Ortúzar, 2002). Overall, these different modes of development and management remain disconnected from each other and, largely, from planning efforts (Sabatini & Soler, 1995; IEUT, 2004).

---

<sup>115</sup> In many ways reminiscent of the “new town” movement in the U.S.; see the Introduction to Chapter IV.

**Table VII-1. Periods of Growth and Forces of Relevance in Santiago de Chile: From Founding to Present**

<b>Broad Historical Period</b>	<b>Urban Planning Influences</b>	<b>Economic Influences</b>	<b>Social Influences</b>	<b>Transport Influences</b>	<b>Structural Patterns of Growth</b>	<b>Size &amp; pop. (000s)</b>
Mercantilist (1541-1750)	- “Law of the Indies” - Defense	- Colonial administration		- The “grid”	- Grid-Based	27 Km <sup>2</sup> 25
Outward Growth (1750-1914)	- Urban consolidation - Urbanization by “Symbol” buildings (Congress, National Library, <i>La Moneda</i> ) - State-individual transactions (Yungay, Club Hipico, Cousiño) - V. Mackenna’s Plan	- Mining wealth - Industrialization - State-Oligarchy ties - Chilean independence - Growing importance of Santiago	- Growth of urban/urbane culture - “Quasi”-aristocracy - Decline in rural craftsmanship, rural-urban migration - Liberal reforms	- Bridge across Mapocho (1800) - Intra-urban steam rail 16 km SWest (1857) and SEast (1891) - First horse tram on Alameda (1858) - Rail to Valparaiso (1863) - Inner belt road (1870s) - 100 kms of horse trams (1900) - first electric tram (1900)	- Cross-Axial, radial development - Increasing segregation of uses	42 km <sup>2</sup> 400
Liberal Model (1914-1950)	- Arrival of “modernism,” “scientific planning” - The Brunner Plan - Industry-provided housing complexes	- “Modernization” Import substitution industrialization, finance, commerce	- Intensifying social inequities	- Tram company merges with electric company (1921), 153 kms - First private bus company (1922) - 223 kms of tram (1937) - Government begins acquiring trams, removing tracks (1945)	Streetcar suburbs, radial development	150 km <sup>2</sup> 1,800
Transnational Capital (1950-Present)	- First Metropolitan Regulatory Plan (1960) - CORMU and urban revitalization (1960s) - Lifting of urban growth boundary (UGB) (1979) - Emergence of real estate “mega-players” - Second Metropolitan Regulatory Plan (1994) - Second Plan modified, lifting UGB (1997)	- Economic crises (1960s, 1970s) - Neoliberal reforms (1970s-80s) - Fairly stable economic growth (1989 onward) - Free trade agreements (1990s-present)	- Social upheaval (1960s) - entrenched segregation (1970s) - middle class “bloom” (1990s) - “social” (i.e., public) housing demand	- Ring Road (1960s) - Metro planned (1960s) - First two Metro lines (1970s) - Major road upgrades (1990s) - Third Metro line (1999) - Highway Concession program (1990s-)	- Polynucleated emergence - Increasing suburbanization - “New Towns” appearing	700 km <sup>2</sup> 5,800

Sources: Historical period categories from Cavric et al, 2004; other information derived from Borah, 1980; Hardoy and Langdon, 1980; de Ramón and Larrain, 1980; Morrison, 1992; Zegras & Gakenheimer, 2000; personal knowledge. Note: final column refers to estimated urban area and population (in thousands) at end of indicated period.

## VII.2 The Making of a Middle Class City

We saw in the previous Chapter that Santiago, relative to the rest of Chile has a lower concentration of poor. Indeed, the city seems to be showing many signs of a full emergence of the middle class. In the 10 years between the 1991 and 2001 origin destination surveys, the average household income grew at an average annual growth rate of 6.5%, from US\$ 4,700 to US\$ 9,000 (in US\$2001)<sup>116</sup>. Based on data from the 2001 origin-destination survey,<sup>117</sup> the average household income in the city is approximately US\$9,000 per year (See Table Table VII-2) and a burgeoning middle class is evident (see Figure VII-2). Nonetheless, despite the fact that over 50% of the households earn, on average, between US\$6,000 and \$13,000 per year, a large share still earn less than \$4,000 per year. In fact, 15% of the households earn, on average, below the minimum monthly wage (approximately \$2,400 per year). Considering the estimated cost for basic urban basket of goods (see previous Chapter, Section VI.1.2), then these households average just enough income for subsistence.<sup>118</sup> On the other extreme, lies the wealthy, a small share of city households, but enjoying average income on par with the industrialized world; with 5% of the households (Income strata C1 in Table VII-2) earning on average roughly the same income as the median US household in 2003.

**Table VII-2. Greater Santiago: Households by Income Category<sup>119</sup>**

Income Category	Income Strata	Average Annual Income (US\$2001)	Number of Households	% of All Households	
<i>High Income</i>	AB	109,059	4,502	0.3%	5.63%
	C1	42,280	80,724	5.33%	
<i>Middle Income</i>	C2	13,200	444,728	29.38%	54.36%
	C3	6,131	378,236	24.98%	
<i>Low Income</i>	D	3,542	372,832	24.63%	40.01%
	E	1,492	232,915	15.38%	
<i>All</i>	All	9,090	1,513,938		

Source: Derived from SECTRA, 2002.

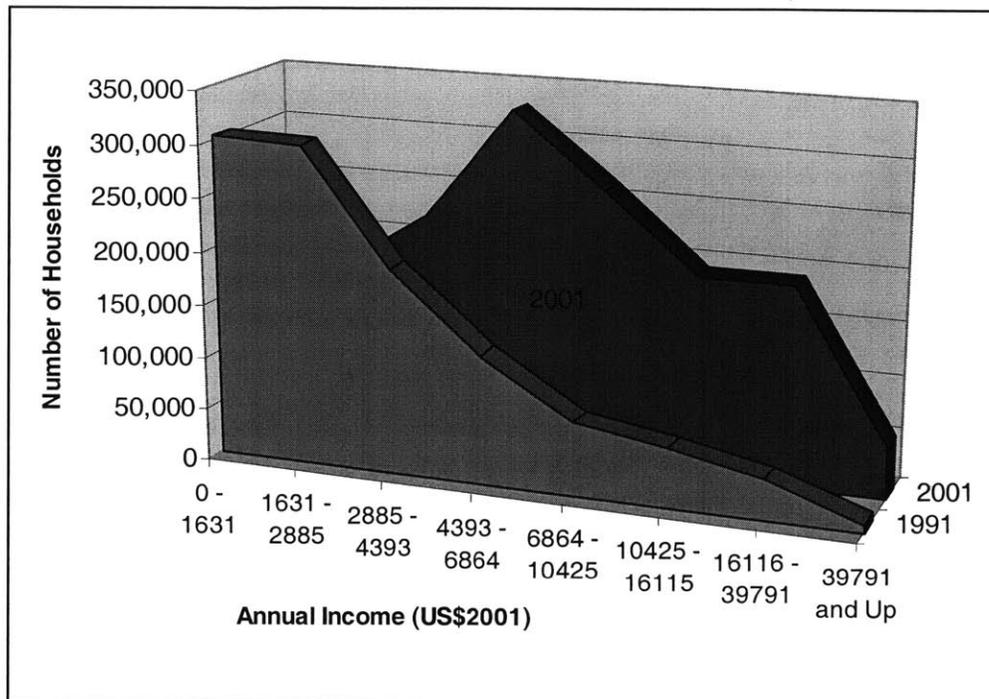
<sup>116</sup> This comparison should be viewed with caution. The 1991 survey only reported income in categories; an average was derived based on the midpoint of each income category for the relevant household. In addition, six percent of households in 1991 reported no income (it is difficult to say whether this no-reporting was biased towards high or low income groups). Finally, the 1991 income categories were inflated to 2001 using the Chilean CPI and then both values were converted to US on prevailing average exchange rates from 2001.

<sup>117</sup> Unless otherwise noted, the data in this section is derived from SECTRA, 1992b and SECTRA, 2004.

<sup>118</sup> The average household size in this income stratum is 2.95; the per capita subsistence cost is \$36 per month.

<sup>119</sup> The categorizations are those used by authorities.

Figure VII-2. The “True” Making of A “Middle Class City”?<sup>120</sup>



Sources: Derived from SECTRA, 1992b; SECTRA, 2002.

### VII.2.1 Spatial Socio-economic Segregation

So, while Santiago’s middle class grows, an important share of poor, indeed very poor, remains, while a high concentration of wealth persists. As discussed in the previous Chapter, Chile still has a high Gini Coefficient of income inequality, 0.57, roughly comparable to other countries in Latin America (such as Colombia, Brazil and Mexico). For Santiago, the Gini Coefficient for household income distribution is approximately 0.5<sup>121</sup>; lower than the national figure, which we would expect, since the national figure reflects likely rural-urban income differences<sup>122</sup>. Nonetheless, this value of 0.5 is still high, particularly in comparison to Western European nations, generally in the range of 0.25-0.35; the U.S. has the highest income inequality of the developed nations, 0.4 (UNDP, 2004).

Not surprisingly, these income disparities manifest themselves spatially. Santiago, like many cities in Latin America is well known for its strong socio-economic spatial segregation, evidenced by the so-called “cone of wealth” (see Figure VII-3), an extension of the traditional upper income migration from their original neighborhoods in the direct west and south of the Plaza de Armas, up into the foothills in the eastern and northeastern parts of the cities (the *comunas* of Las Condes, Vitacura, Providencia, Ñuñoa and La Reina). In recent years, as the cone of wealth has run into topographical barriers (the

<sup>120</sup> The 1992 Origin Destination Survey reported Household income by range. Those ranges were brought into 2001 pesos using the Chilean Consumer Price Index (IPC; INE, 2004). Those values were then converted to US\$ at the 2001 average observed exchange rate.

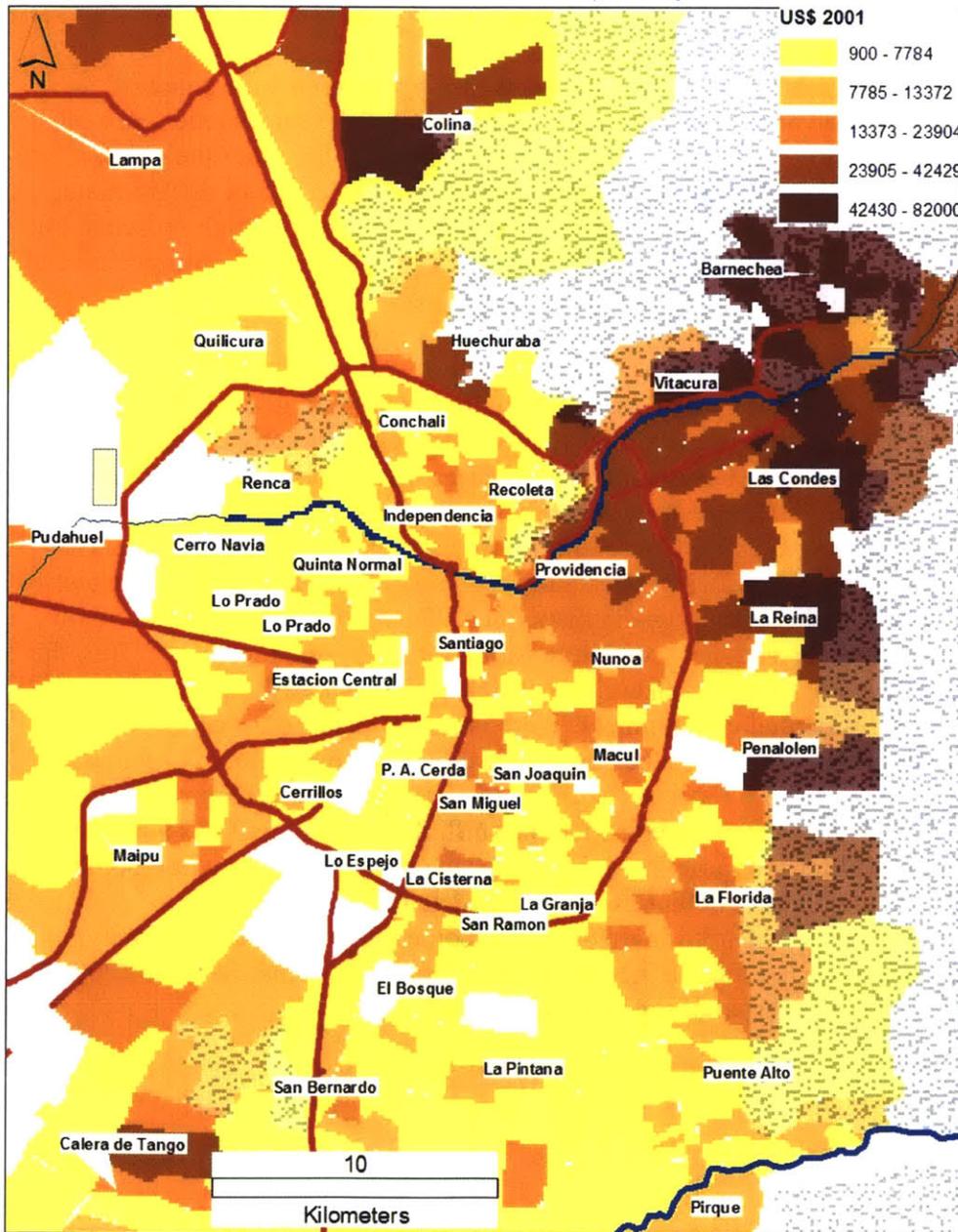
<sup>121</sup> Calculated from the 2001 OD Survey.

<sup>122</sup> The Argentine urban figure, for comparison, is 0.52 (UNDP, 2004)

Andes), two important phenomena have occurred: densification of the original first tier wealthy suburbs through lot consolidation and apartment building construction (the “park city” discussed further below); and the middle and upper middle classes have begun searching for new location options – some following the foothills South into Peñalolén and La Florida and, now, jumping into the rapidly developing North.

**Figure VII-3. Average Household Income in Greater Santiago**

*Data averaged for the travel analysis zone (TAZ). The red lines represent major limited axis highways; the gray shaded areas are primary topography; blues lines are Mapocho (north) and Maipu (south) Rivers; white areas have no information available; the rectangle in the West (in Pudahuel) is the airport; the comuna names, but no formal jurisdictional boundaries, appear.*



Source: Derived From SECTRA, 2002b.

Some evidence suggests a decline in the degree of spatial segregation (see, e.g., Sabatini, 2000). We can get a sense of the extent of spatial segregation and any changes over time by comparing evidence from the two household travel surveys. Farah et al (1993), analyzing the 1991 Santiago origin-destination, survey proposed a segregation index, measured at the *comuna* level. The Index is similar to an entropy or dissimilarity measure, basically gauging the degree to which the socioeconomic composition of a *comuna* matches the socioeconomic composition of the whole city.

The Index takes the form:

$$I_i = \left( \sum_j (p_{ij} - P_j)^2 / P_j \right)^{1/2} \quad (7.1)$$

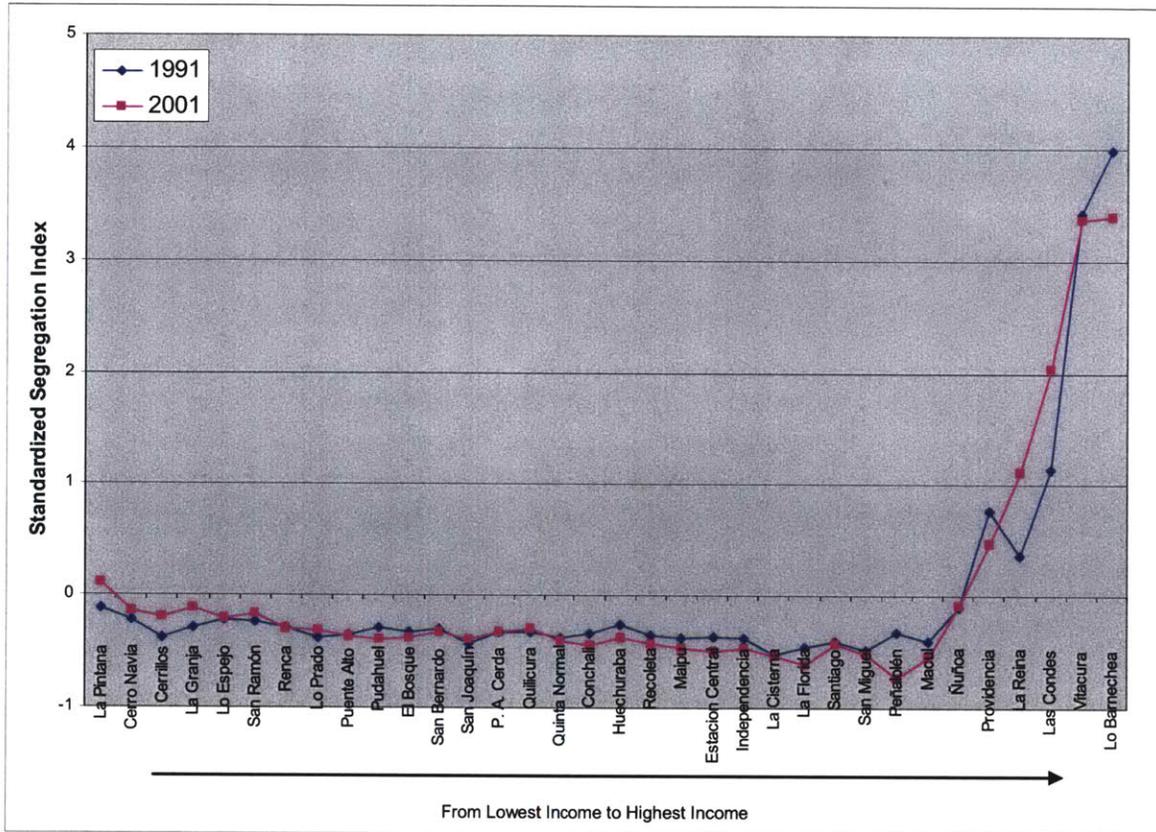
where  $I_i$  represents the segregation Index for *comuna*  $i$ ,  $p_{ij}$  represents the share of households from socioeconomic stratum  $j$  in *comuna*  $i$ , and  $P_j$  represents the share of households from stratum  $j$  in the city. The lower the value of  $I$ , the more the given *comuna* reflects the overall composition of the city. The Index does not differentiate, necessarily, whether or not a given *comuna*'s dissimilarity is due to a high presence of poor or a high presence of wealthy, but given the overall socioeconomic composition of the city, a very high score will, in general show a high concentration of wealth.

I calculated the index using the same socioeconomic categories as Farah et al. (1993) (those from the 1991 OD Survey and shown in Figure VII-2); but, given the change in proportions among the *comunas*, the values themselves are not directly comparable across the two years. As such, I standardized the scores; in this case, a lower value still represents less segregation. The results, depicted in Figure VII-4 with *comunas* ranked in ascending order of average (2001) Household income from left to right, bear some interesting observations. Overall, 2001 has a lower standard deviation, which suggests some evening out of the between-*comuna* disparities. The wealthiest *comunas* remain highly segregated, and even suggest some intensification (e.g., in La Reina)<sup>123</sup>. But, the least segregated *comuna*, by this measure, is Peñalolén, largely a result of middle and upper middle class residential developments there in recent years (not that these are integrated developments, per se, but the *comuna* profile is more integrated) – a marked change from its 1991 level. La Florida, the focus of very strong suburbanization pressures in the past decade, also experienced considerable shift. Figure VII-5 shows a map of the Index value calculated for the same 34 *comunas*, for the year 2001. So, while both the very high and very low income *comunas* remain segregated, some decrease in segregation seems to have occurred in the middle income range *comunas*; this may, in part, be a result of increasing middle income growth. Note, again, that Sabatini (2000) finds some signs of reduced spatial segregation as well.

---

<sup>123</sup> Note, however, that this metric does not capture socio-demographic changes within *comunas*.

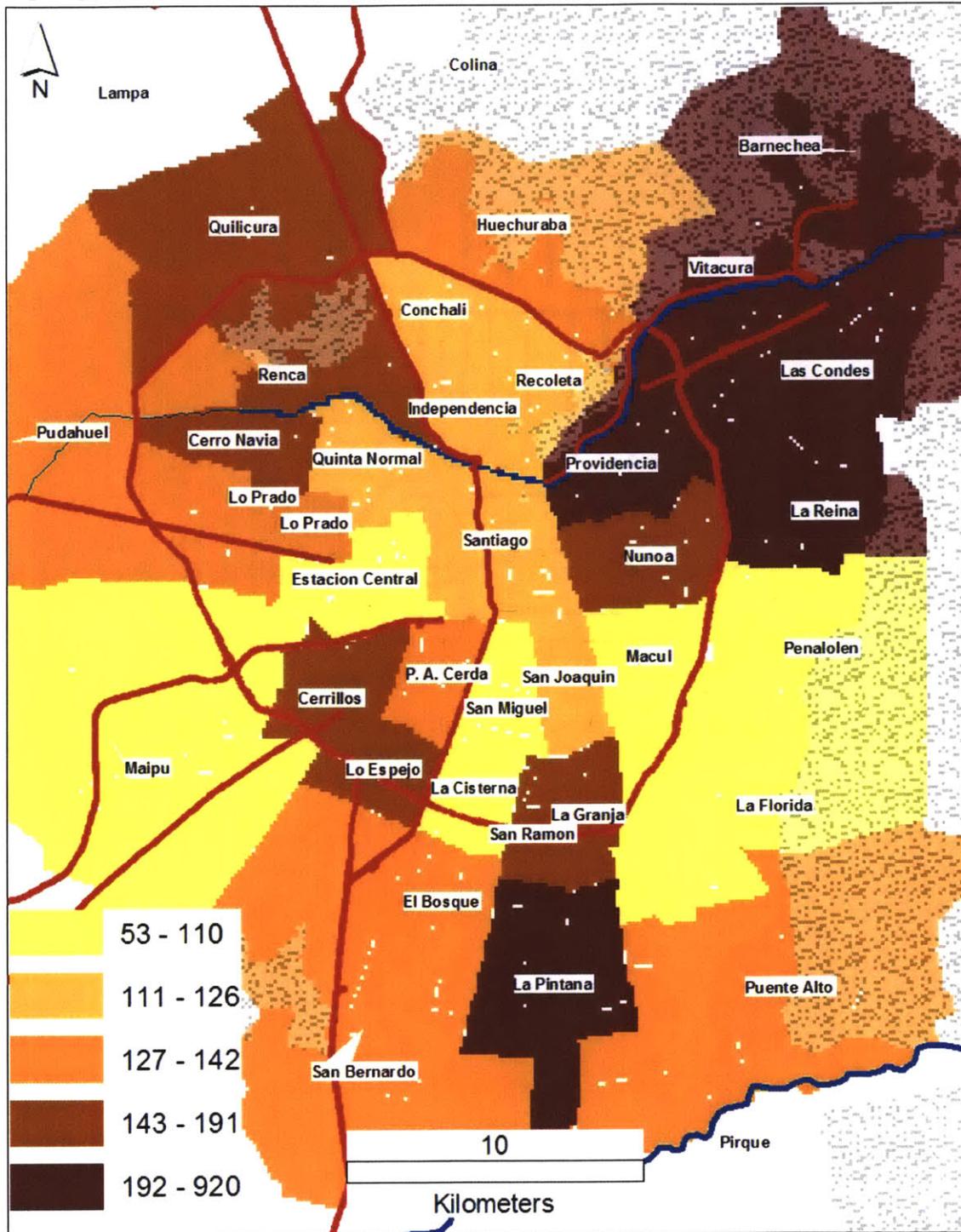
Figure VII-4. Standardized Segregation Index by *Comuna* in Greater Santiago



Source: 1991 values originally from Farah et al, 1993; 2001 calculated from SECTRA, 2002.

**Figure VII-5. Comuna Segregation Index: 2001**

*Map Represents Index Values by Quintile Calculated for the Comuna*



Source: Calculated based on equation (7.1) with data from SECTRA, 2002. Note: *Comuna* boundaries may not be precise.

## VII.3 The City Structure, Form, Design

Following Chapter IV's definition of basic spatial scales – metro-, meso-, and micro- – and associated built environment characteristics – termed, respectively, urban structure, urban form, and urban design – this Section provides a look at relevant characteristics for Santiago.

### VII.3.1 A Note on Data Sources and Data Preparation

The land use data presented in this Section come from national tax records and business and land use permits (as reported to Municipal governments) and include information (e.g., type of use, floor space constructed) for roughly 1.3 million residences and 400,000 non-residential land uses, geo-coded at the street address level or sometimes the census block level.<sup>124</sup> Land uses included 17 general categories (e.g., residential, manufacturing, public administration), for each registered activity, information included the constructed floor space and the relevant plot size. The data are for the year 2001; unfortunately, land use activity data were only available for 34 *comunas*; the rapidly suburbanizing Northern *comunas* of Colina and Lampa and the Southern *comunas* of Calera de Tango and Pirque (see Figure VII-3) are, therefore, excluded from the analysis. A 1999 digital road map and “curb cut” were also provided, from which intersection counts, road widths and lengths were derived.<sup>125</sup> Highway additions and upgrades as of 2001 were added to the 1999 map.

Additional land use coverage data comes from a map of open spaces, compiled originally by environmental authorities in 1998.<sup>126</sup> This map provided a surprisingly good coverage of greenspaces (including parks, plazas, cemeteries, agricultural land, other greenspaces and sports facilities) within a larger land use map that included other zoned uses. The presence of the greenspaces in this MINVU map were corroborated via an orthophoto.<sup>127</sup>

The geo-coded land use activity points and the open space polygons were used to “build” the city blocks in the following manner: (1) using the “curb cut” (see footnote 125), a “pseudo block” map was developed using ArcToolbox utilities; this “pseudo block” map

---

<sup>124</sup> The database was provided to the author by SECTRA. Note, the geo-coding of the land use activity points (with each point representing a registered activity (residential or non-residential land use) was not 100% accurate. Since the data points were geo-coded based on street addresses and numbers, those activity points that could not “find” the proper address (the street map was from 1999; while the activity points were from 2001) remained “orphaned.” This phenomenon primarily occurred for points in the rapidly growing areas. Considerable effort was made to relocate those points based on the recorded street addresses and updated street maps, but room for error clearly remains.

<sup>125</sup> Also provided by SECTRA; “curb cut” refers to a polyline file outlining all the street centerlines, with the width of the outline based on the coded street class (i.e., alley, street, avenue, etc.).

<sup>126</sup> This information, a database and polygons, was provided to the author by the Ministry of Housing and Urban Development (MINVU).

<sup>127</sup> The Orthophoto provided (also by SECTRA) was for the year 1997. The land use coverage information came from authorities' field survey efforts to see the degree to which actual land uses matched zoned land uses (open spaces); multiple queries were carried out on the database to extract actual land uses, based on the recorded field survey observations contained in the database. For example, only zoned open spaces that were surveyed to have some tree/grass coverage, not abandoned, were considered.

was further corrected manually according to an INE Census block map for 2001;<sup>128</sup> (2) the activity points were then allocated to a corresponding “pseudo block,” based on proximity and the open space polygons were similarly allocated to the “pseudo blocks;” (3) based on these allocations, the “pseudo blocks” were “built.”

The resulting “constructed” “pseudo blocks” were used in two ways. First, they were used to develop a 250 meter by 250 meter grid-cell based coverage of the city; the grid cells were constructed by allocating the share of a given “pseudo block’s” characteristics to each grid cell based on relative land area (using the grid cells as an overlay); intersections and road characteristics were also allocated according to the grid cell they “belonged” to.<sup>129</sup> The purpose of developing the grid cells was to facilitate statistical exploration of built environment characteristics (discussed further below) while trying to diminish effects related to the modifiable areal unit problem (as discussed in Chapter V; see, e.g., Robson, 1969; Zhang and Kukadia, 2005). The blocks were also used to develop the land use characteristics for the travel analysis zones (TAZs), allowing block morphology characteristics to be included in TAZs (together with the street and intersection metrics as well). The results of the “pseudo block” and grid cell construction were partially corroborated via the 1997 orthophoto and site visits.<sup>130</sup>

### VII.3.2 Macro Scale: Urban Structure and Evolution

First at the macro scale, perhaps the most relevant characteristic, still, is Santiago’s fairly compact size. The international evidence presented in the previous Chapter confirmed this to some degree (in terms of metropolitan-wide population densities). Taking a closer look, we can see that roughly 95% of the population within the 38 *comunas* of Greater Santiago live within an approximate 15 kilometer radius of the central business district (*Plaza de Armas*). In other words, with 5.4 million people across an urbanized area of approximately 800 square kilometers, the *gross* population density for Greater Santiago is on the order of 65 persons per Hectare.<sup>131</sup> In basic physical form and structure, then, the Santiago Metropolitan appears somewhat similar to the Chicago Metropolitan Area (CMA), circa 1960. In 1960 the CMA covered approximately 650 square kilometers, with a population of approximately 5.2 million people, or a gross population density of 80 persons per hectare.<sup>132</sup>

---

<sup>128</sup> The INE (National Statistics Institute) Census block map was provided to the author by MINVU. Unfortunately, due to the multiple original sources for the Census block maps (which were supplied individually for each *comuna*) and different original projection systems (for the MINVU and SECTRA maps), the INE Census blocks could not be made to accurately enough match the land use activity points (geo-coded to the SECTRA-source street file). As such, the “pseudo block” creation, based on the SECTRA files provided the best solution.

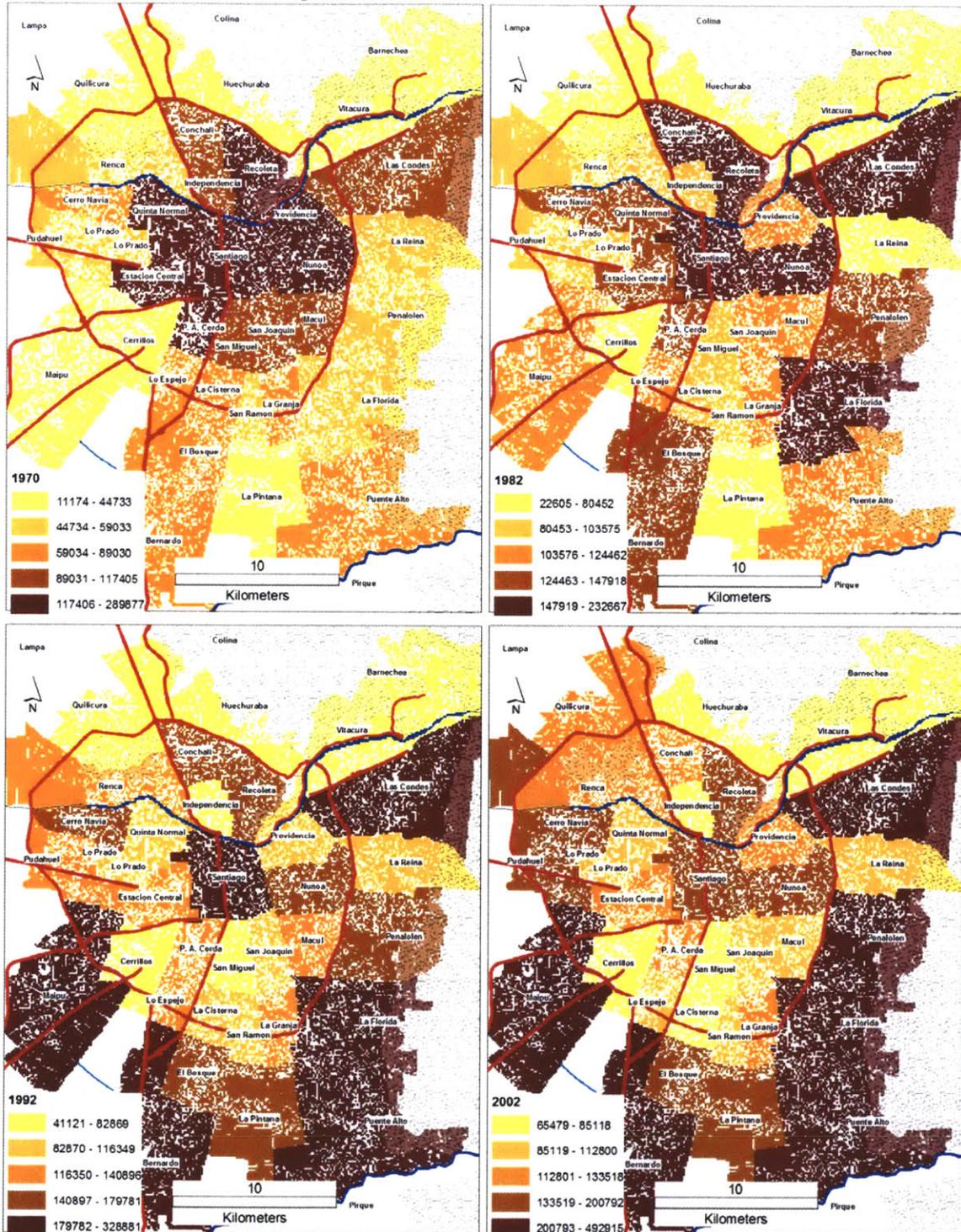
<sup>129</sup> The author is indebted to Xiongjiu Liao for developing and building the grid cells.

<sup>130</sup> The site visits were carried out in December 2004; primarily to look at very large concentrations of commercial areas; in all cases the results were verified; some corrections of activity point allocations were made. Sincere thanks to Daniel Castillo for his help with the site visits.

<sup>131</sup> Based on INE definition of urban area.

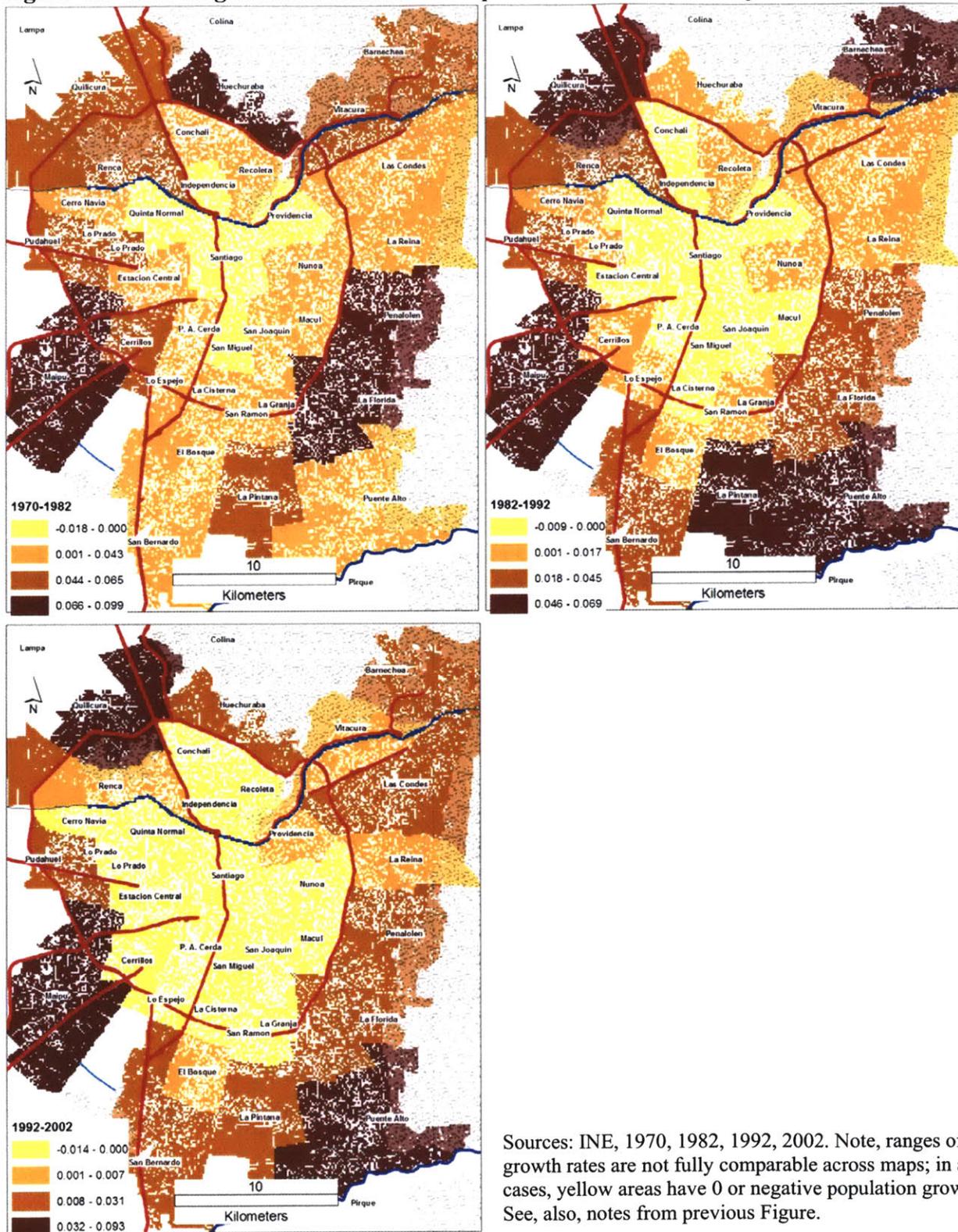
<sup>132</sup> The Chicago estimates come from Levinson and Wynn (1963) and are estimates of land area and gross densities based on the net residential densities and population reported by those authors for Chicago in 1956.

**Figure VII-6. Comuna Population 1970-2002**



Source: INE, 1970, 1982, 1992, 2002. Note, population ranges associated with each color category are quintiles (i.e., the 40% of the comunas with the most population in a given year are represented by the two darkest shades). The population size ranges are not the same across the maps. Only 34 comunas are included; comparable data was not fully available for Colina, Lampa, Calera de Tango, Pirque. The white space within the comunas are unfortunate residuals from block map consolidation.

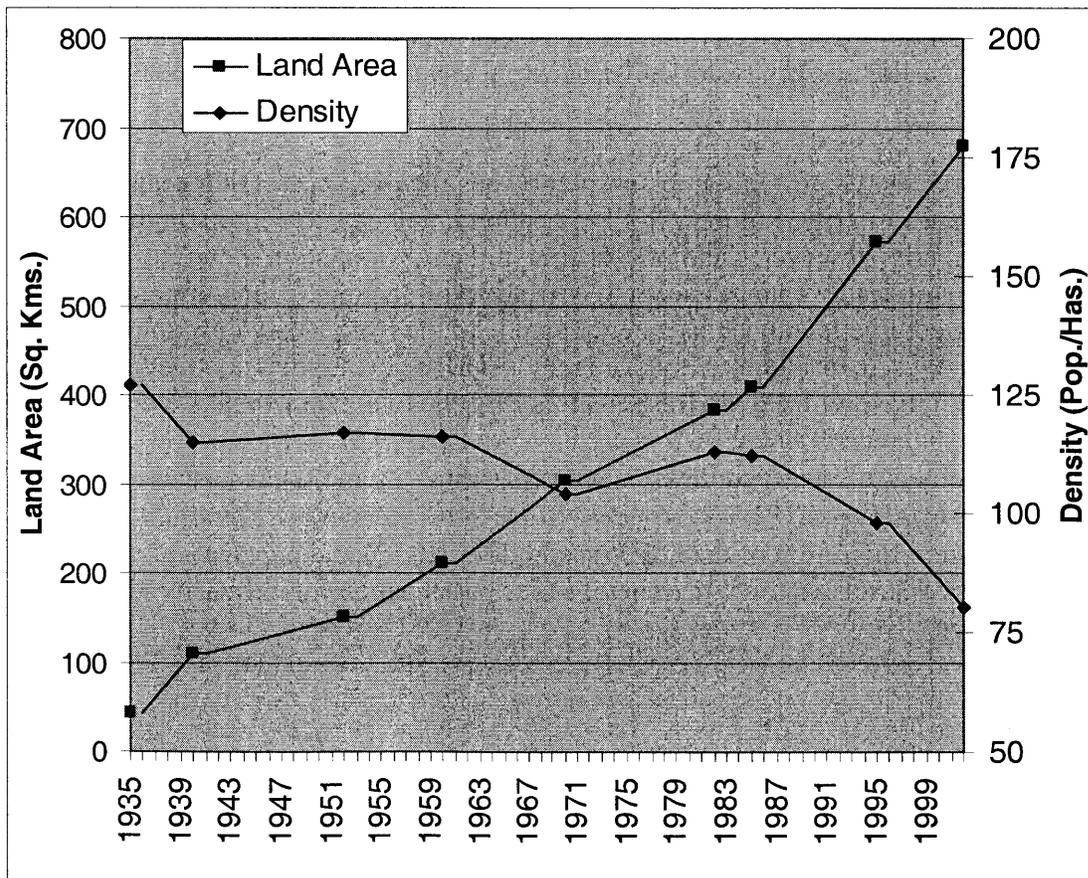
**Figure VII-7. Average Annual Intercensal Population Growth Rates by Comuna**



Sources: INE, 1970, 1982, 1992, 2002. Note, ranges of growth rates are not fully comparable across maps; in all cases, yellow areas have 0 or negative population growth. See, also, notes from previous Figure.

The predominant structural pattern of evolution in Santiago has been, as discussed above, urban outgrowth/expansion. Figure VII-6 and Figure VII-7 provide a stark view of these trends, as indicated by *comuna*-level population levels, and average annual population growth rates. In Figure VII-6, we can see the contrast in population concentrations from 1970, where the majority of the city's population lived in the *comunas* within an 8 kilometer radius from the *Plaza de Armas* (with the exception of Las Condes); by 2002, nearly the inverse can be seen, with the most heavily populated *comunas* primarily on the Southern outskirts. The larger size of the *comunas* on the edge play some role here, as they have more room for population than the traditional consolidated inner-city *comunas*. However, looking at average annual growth rates between the four censuses (Figure VII-7), we can see an increasing number of inner-city *comunas* losing population over time, with nearly all *comunas* inside the Vespucio Ring Road with zero or negative population growth rates between 1992 and 2002. These data do not account for the possible influencing factors of, for example, changing household size, so the central *comuna* population losses do not necessarily also mean declining numbers of households. The implications of these structural trends on overall urban area size and approximate population densities can be seen in Figure VII-8 (note that the beginning of the apparent precipitous decline in population density at the end of the 20<sup>th</sup> Century coincides with the lifting of the urban growth boundary in 1979), leaving one to wonder: will the current tendencies continue?

**Figure VII-8. Evolution of Land Area and Population Density in Greater Santiago**



Sources: Crocco, 1950, DEC, 1960; INE, 1970, 1982, 1992, 2002; Urbe, 1995; Aguirre & Castillo, 2004.

### VII.3.3 Meso Scale: Urban Form

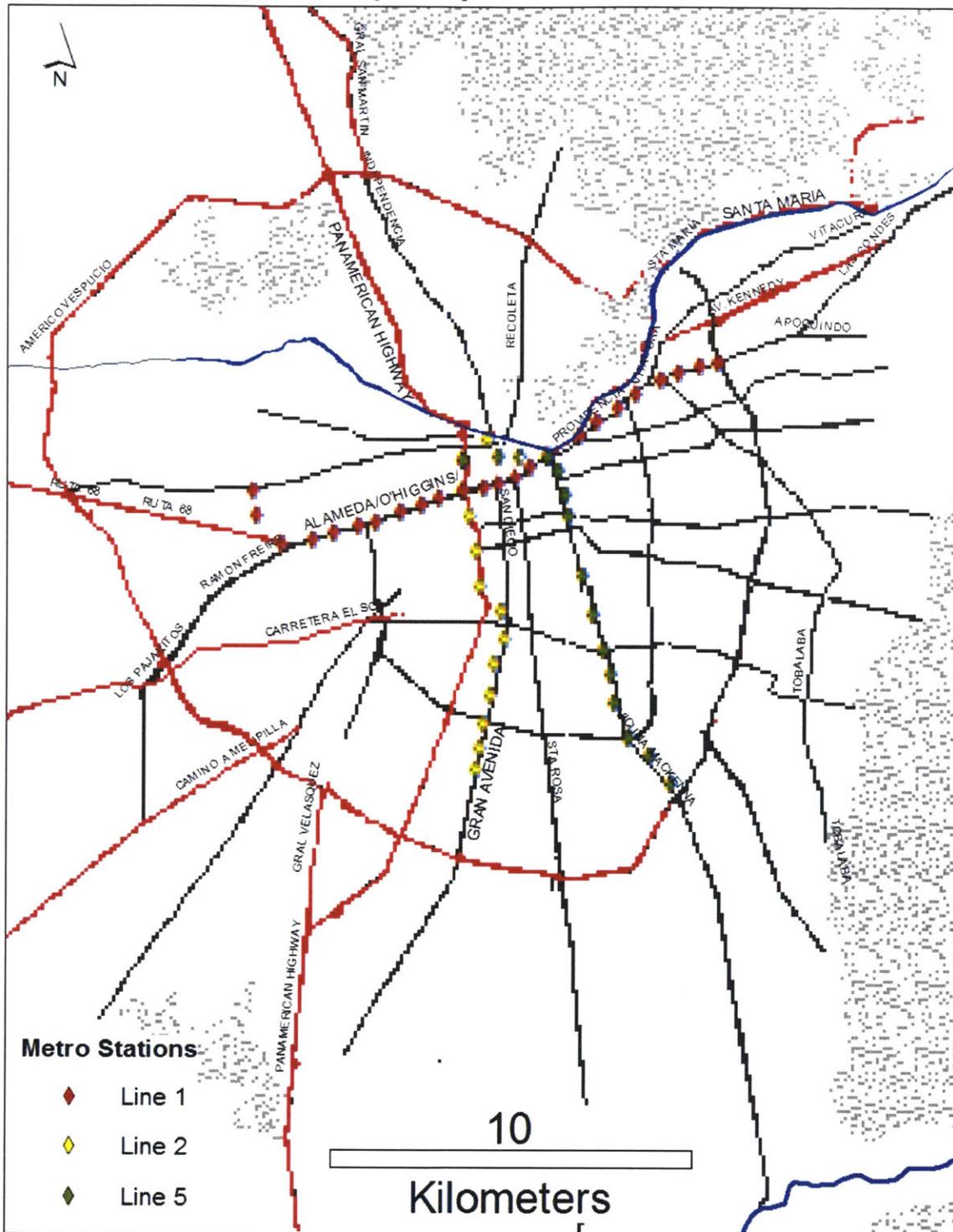
As mentioned in the introduction to this Chapter, Santiago's development followed major transport corridors (originally tram-lines, later roads and major avenues), primarily radiating outwards from the original colonial grid. This development pattern produced two salient urban form traits: a dense concentration of urban functions (commercial, business, administrative, social services etc.) in the CBD, with some radial development of commercial and industrial uses. Shopping areas developed as natural extensions of early commercial streets, such as San Diego street extending to Gran Avenida in the South and a major orientation along the original East-West corridor Alameda (O'Higgins)-Providencia (which extends Eastward as Apoquindo-Las Condes and Westward as Pajaritos; see Figure VII-9). Figure VII-10 shows concentrations of commercial land uses, as well as the dates of foundation of major shopping malls. As might be expected, the city's first malls – in the early 1980s – appeared in the upper income neighborhoods of the East before following the suburbanization South and Southeast and, most recently, in the North along the upgraded ring road.

Regarding industrial uses, these historically developed along major rail, including the original inner-ring rail belt immediately South of the CBD, and then followed intercity road infrastructure (primarily the North-South Panamerican Highway running through the city and the roads to the coast. Industrial uses as of 2001 continue to reflect the original industrial zones from the 1960 Intercomunal Plan (see Figure VII-11; note that the industrial zones from the 1960 plan may well have already been existing industrial areas at the time); many of the inner-city industrial uses, however, are in decline and large swaths of brownfields exist in historically industrial *comunas*, such as San Joaquín (see MIT-CDD, 2003).

Since at least the 1960 metropolitan plan, rhetoric has focused on creating a sub-centered, polycentric urban form (see Figure VII-13 indicating intended sub-centers in the 1960 plan). Until recently, however, the mono-centric, radial development pattern predominated. Noticeable changes seem to coincide with the major road upgrades, particularly the completion and subsequent upgrade to the Ring Road Vespucio as well as important East-West axes (such as Av. Kennedy). These developments, together with increased wealth may hold primary responsibility for the two major breaks evident in the monocentric/radial development:

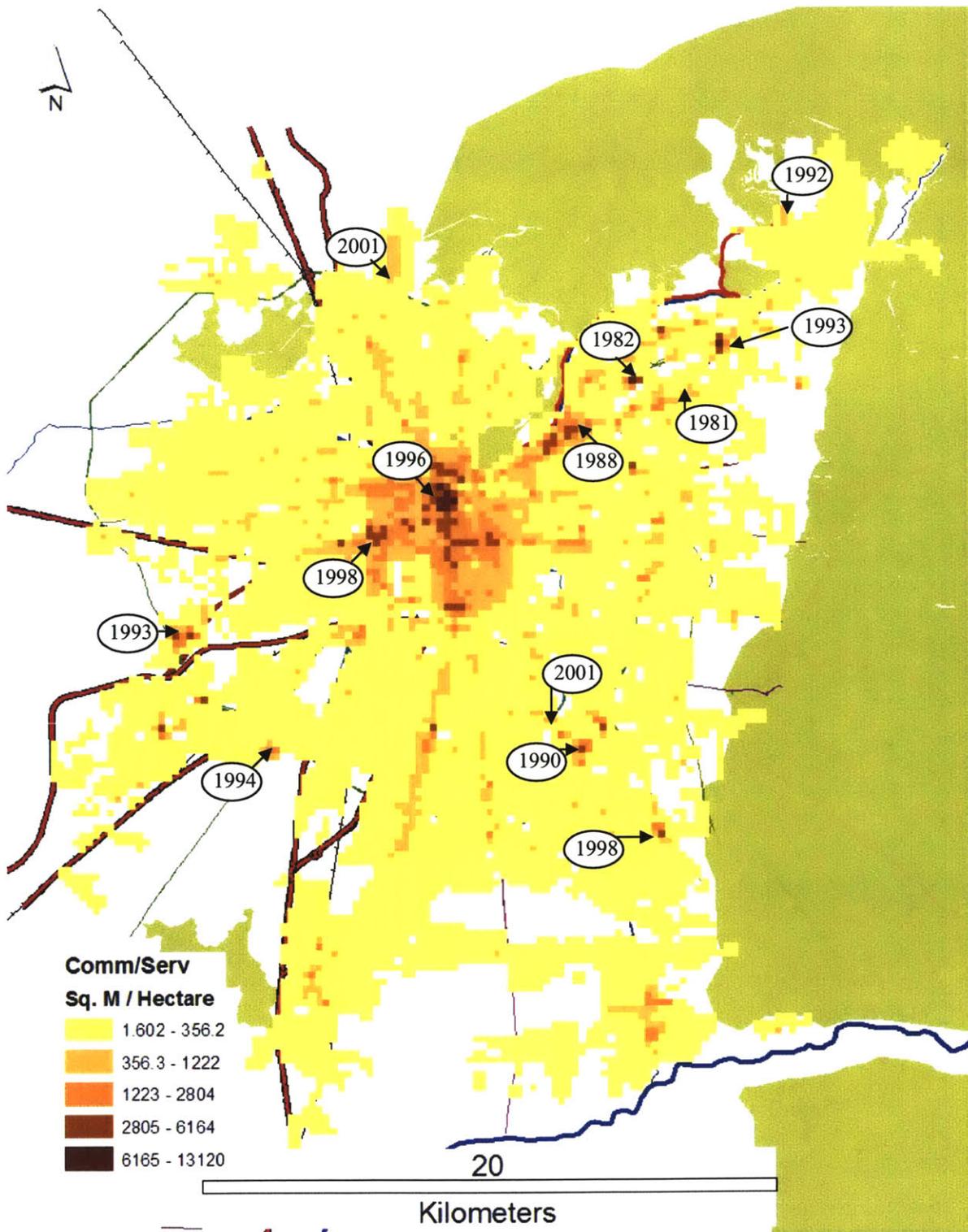
- the sprouting of major commercial centers (primarily malls), as discussed above; and,
- the Eastern migration of the CBD (see Figure VII-12) and a growth of non-central business districts, namely peripheral office parks, emerging primarily along the ring road.

**Figure VII-9. Santiago's Primary Transportation Infrastructure: 2001**



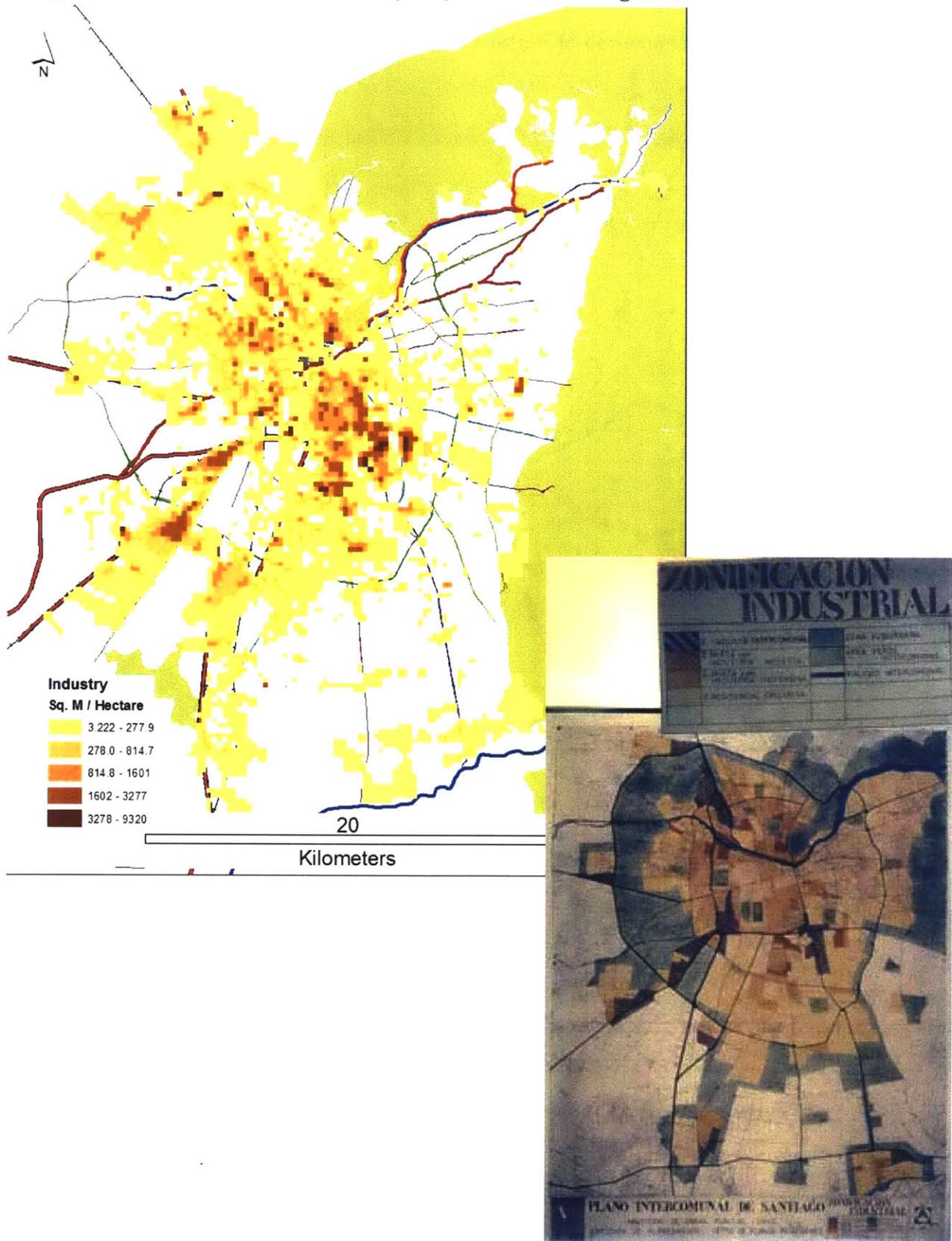
Note: Thicker (Red) Lines are limited access highways; the Vesputio Ring Road remains in the process of being upgraded in the South and East; Thinner (Black) lines are principal Avenues. The grey areas represent major topography and the blue lines rivers.

**Figure VII-10. Commercial Activities and Malls in Greater Santiago: 2001**



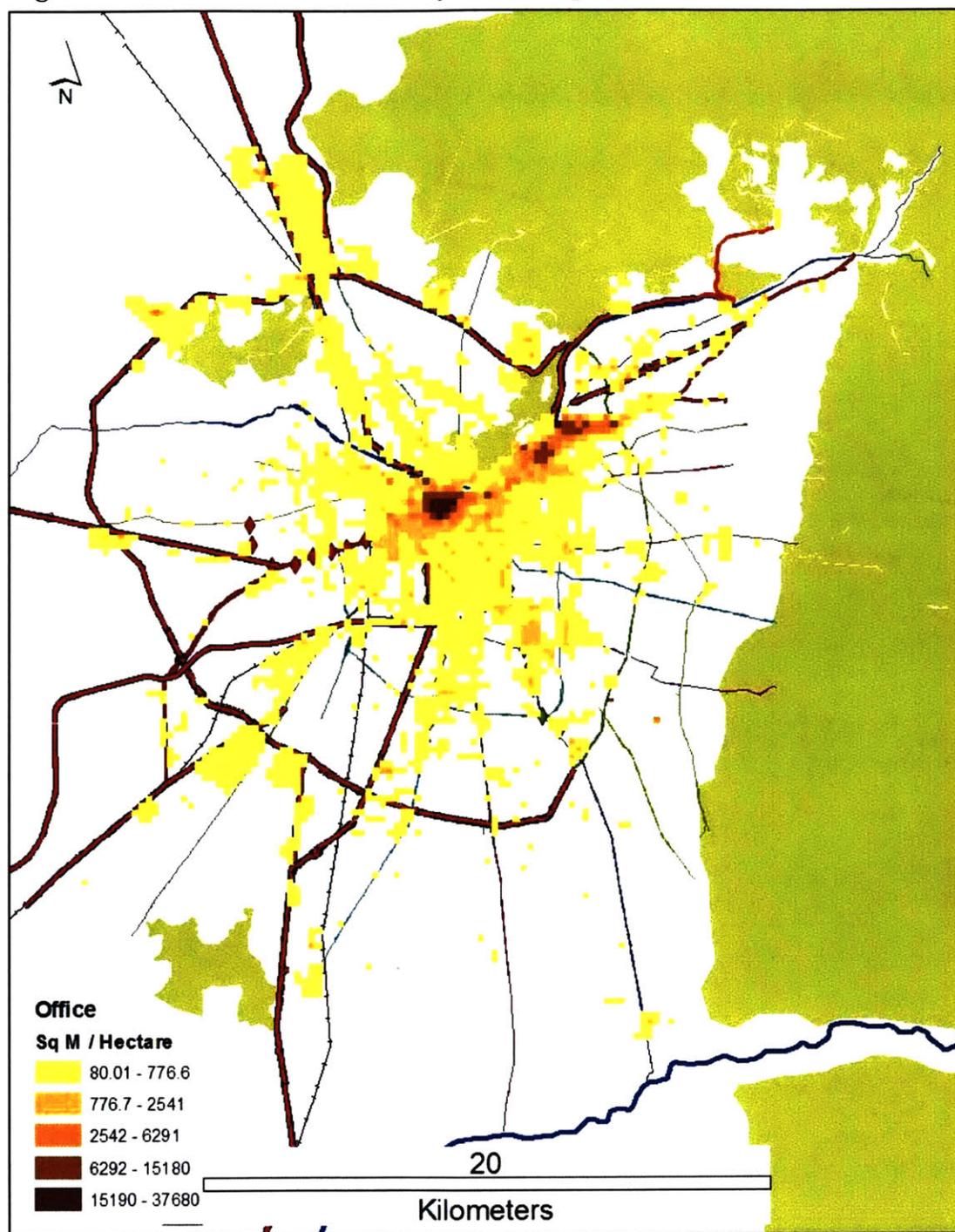
Note: Dates indicate major shopping malls, year of founding. Source for years: up to 1998 from Sabatini (2000); more recent years, authors' estimates.

**Figure VII-11. Industrial Activities (2001) and 1960 Zoning Plan**



Source for 1960 Plan Map: Parrochia and Pavez, undated.

**Figure VII-12. Concentration of Major Office Space**



Note: In this figure, only areas with greater than 80 square meters of office space per hectare are shown.

Figure VII-13. Proposed Sub-Centers in the 1960 Intercomunal Plan



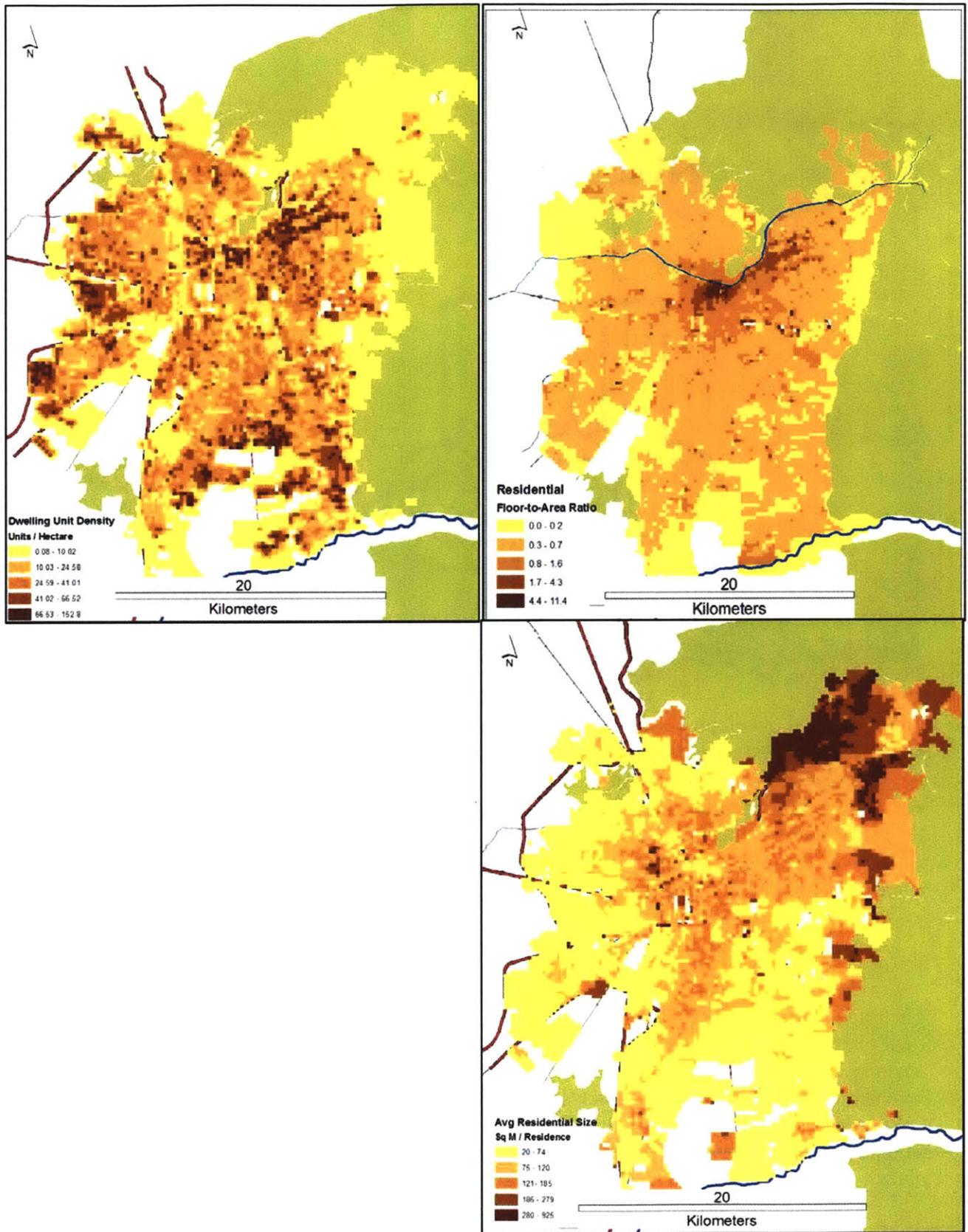
Source: Parrochia and Pavez, undated.

For residential development, three form-related patterns appear (see Figure VII-14):

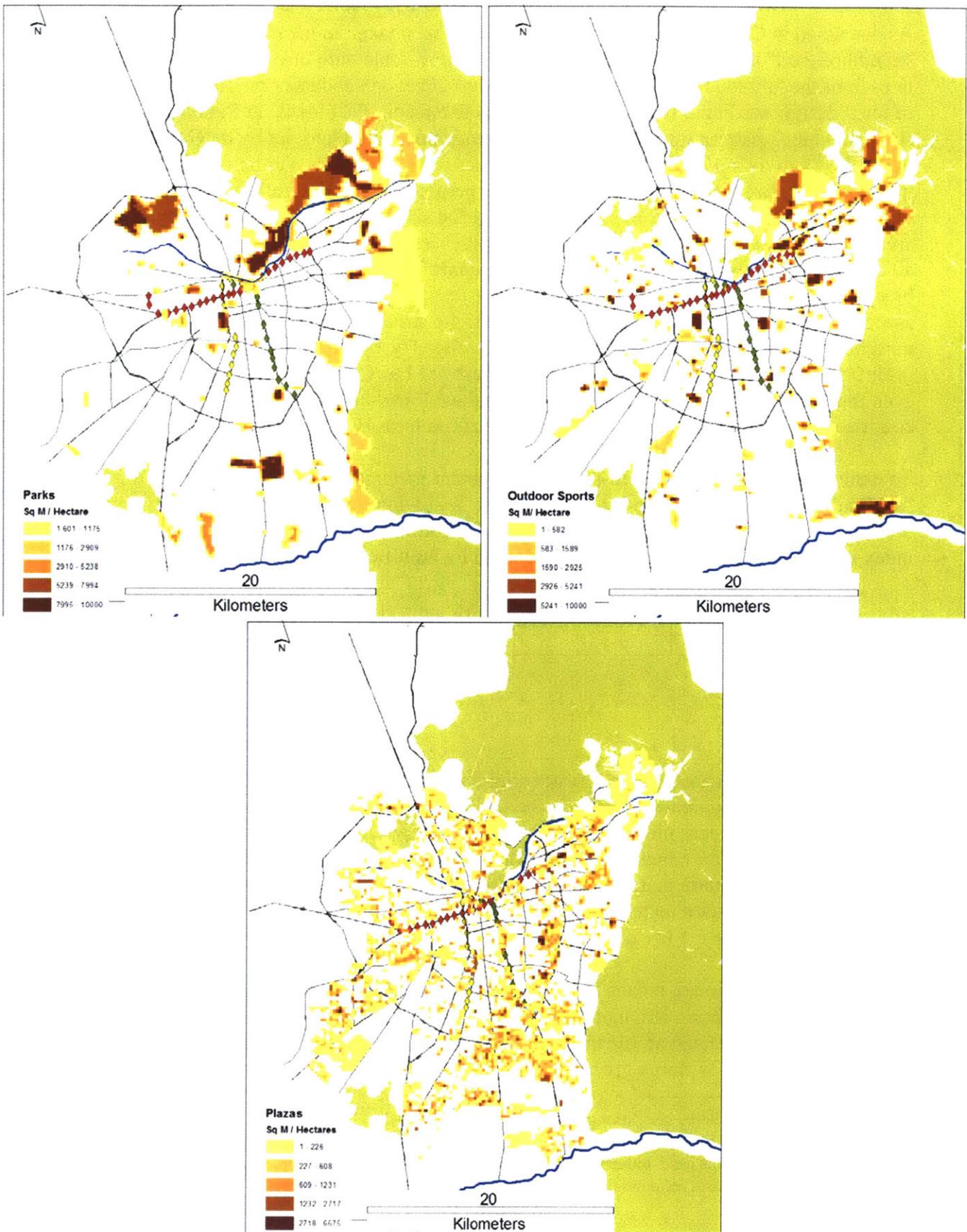
- a general dwelling unit density pattern consistent with the socio-economic spatial segregation and primarily peripheral concentration of lower income groups;
- a highly concentrated area of multi-story residential apartment buildings (evidenced by residential floor-to-area ratios), primarily in the historical CBD and the original first tier Eastern upper class suburbs (the “park city,” discussed further below); and
- a concentration of large residences (measured by average residential size), entirely consistent with the “cone of wealth,” but showing pockets growing in the southeastern foothills, emerging in the suburbanizing North (and South), with some remaining in the original downtown neighborhoods of “aristocratic” Santiago.

The relative distribution of open space – parks, sporting fields, and, plazas – provides a final piece to the general urban form picture. Here, a clear picture emerges of the relative amenity enjoyed by the higher income areas, with a large amount of parkspace concentrated in the Eastern foothills; sports facilities, particularly golf courses (also a polo field) also expectedly cluster in this area, while *futbol* (soccer) fields, naturally, add an equalizing distribution of sports facilities. The great equalizer, however, comes from plazas, the one public/open space that shows a fairly even distribution across the city.

**Figure VII-14. Residential Form: Dwelling Unit Density, Floor-Area Ratio, Avg Size**



**Figure VII-15. Indicators of Urban Form: Parks, Sports and Plazas**



### VII.3.4 The Micro Scale: A Glimpse at Urban Design

As discussed in Chapter V, many approaches have been taken to measure micro-scale, “neighborhood” urban design. Here, we present micro-scale built environment measures in each of the “three D’s” (see Chapter V): *design*, *diversity*, and *density*. To give sense of local design, we begin with the street and, by extension, the blocks. In Santiago, the street and block pattern inherited from the *conquistadores* and laid out by de Gamboa, Pedro de Valdivia’s *alarife* (see Figure VII-1) has endured in time and perpetuated itself in space. One can appreciate the degree of this perpetuation in Figure VII-16, depicting close-up of blocks and block morphology, using the simple morphological indicator of area over perimeter (A/P). The A/P metric provides a rough measure of block “porosity”; all else equal, a larger value signifies a “more square” block; larger values connote larger block sizes.<sup>133</sup> This basic measure shows that, except for very large blocks primarily associated with parks or other recreational areas, the street network and block morphology evidences little variation across the city. The primary exception to this gridiron perpetuation is the eastern foothill suburbs of Las Condes and Lo Barnechea; but even there the only significant variation is found well into the foothills, where the continuous curvilinear and “loop and cul-de-sacs” patterns become evident.

To explore the diversity of micro-scale development patterns, we use a land use “dissimilarity” or diversity “index.” This index, following Rajamani, et al. (2003), aims to capture the mix of uses relative to a perfect distribution of uses.<sup>134</sup> In this case, the index includes six different land uses, measured by built floor space:

$$DI = 1 - \left[ \frac{\left| \frac{r}{T} - \frac{1}{6} \right| + \left| \frac{c}{T} - \frac{1}{6} \right| + \left| \frac{h}{T} - \frac{1}{6} \right| + \left| \frac{o}{T} - \frac{1}{6} \right| + \left| \frac{p}{T} - \frac{1}{6} \right| + \left| \frac{s}{T} - \frac{1}{6} \right|}{\frac{5}{3}} \right] \quad (7.2),$$

where:

- $r$  = square meters of residential floor space
- $c$  = square meters of commercial floor space
- $h$  = square meters of health floor space
- $o$  = square meters of office floor space
- $p$  = square meters of public administration floor space
- $s$  = square meters of social services floor space and
- $T = r + c + h + o + p + s$

A value of 0 for this index means that the land in the area has a single use and a value of 1 indicates perfect mixing among the six uses. While this measure can be depicted at, and have patterns detected at, the meso-scale, it attempts to measure effects at the micro scale (mixing of uses within a given area – in this case the 250 meter grid cell).

<sup>133</sup> The A/P measure correlates very strongly with the “equivalent radius”:  $r = \sqrt{(\text{Area}/\Pi)}$

<sup>134</sup> Note that this measure is theoretically similar to the segregation index from the last sector and also to entropy-type indices. In this case, industrial uses were omitted from the calculation, since the purpose was to try to capture variations in residentially-oriented neighborhoods.

**Figure VII-16. A Patchwork of Santiago's Block Morphology**

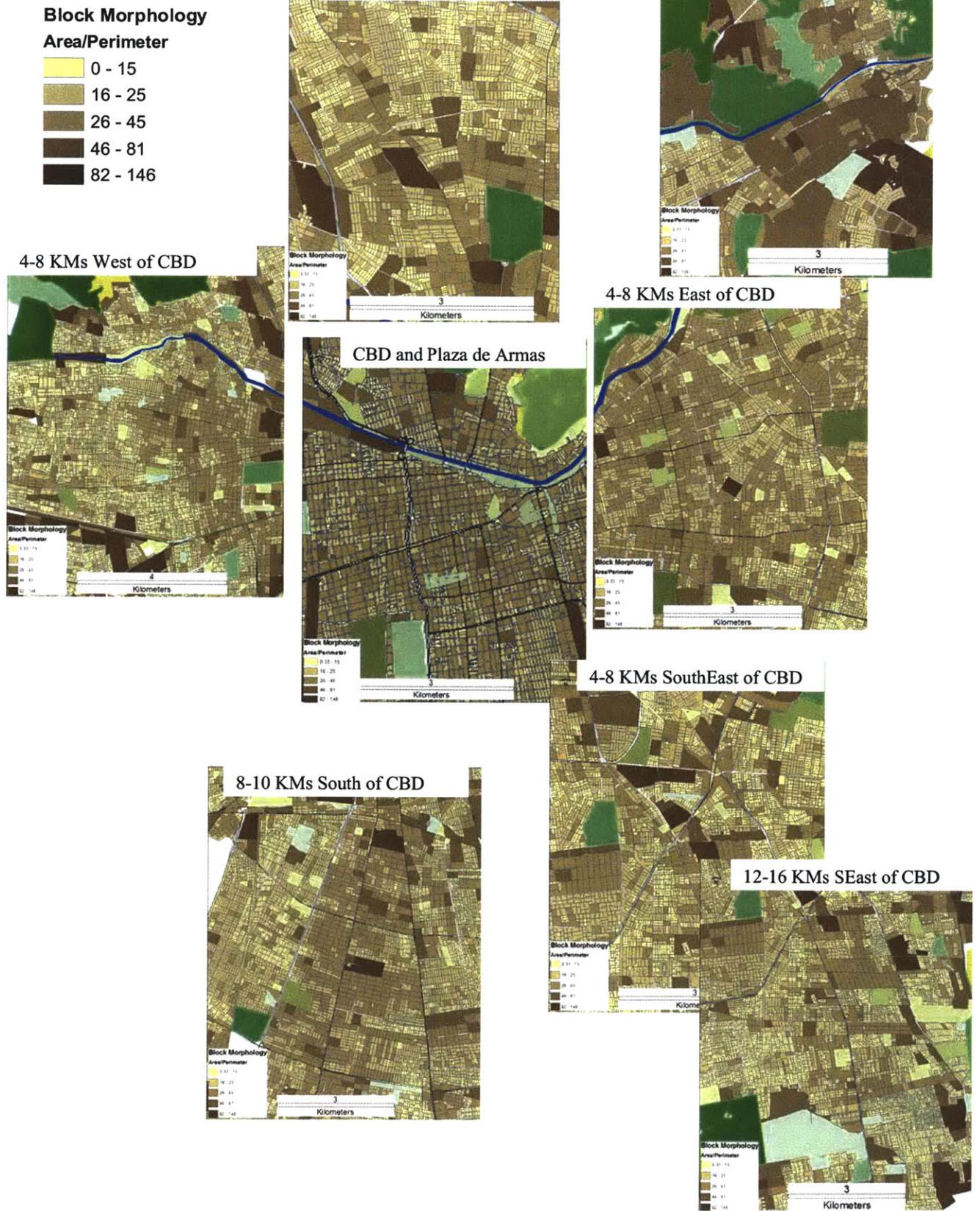
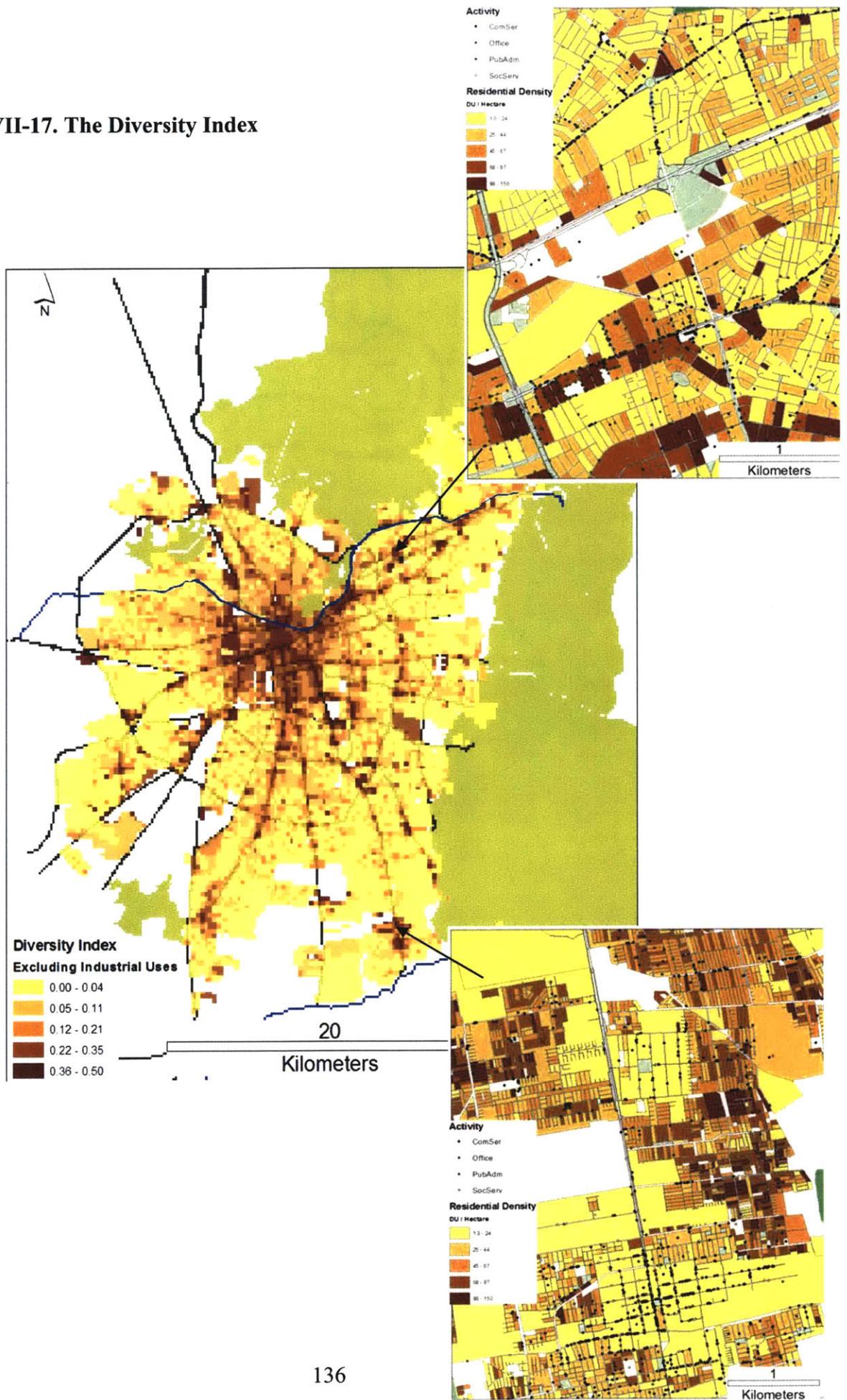


Figure VII-17. The Diversity Index



The diversity index actually reveals both meso- and micro-level features of Santiago's built environment. At the meso-level, it confirms the continued mono-centric and radial patterns of concentration, discussed above. At the micro-level, it suggests that Santiago has fairly large areas of, primarily, residential use, with an apparently low degree of land use mixing. Note, however, at least one problem with this metric as applied in this case. By using the floor area instead of the number of activities of the various land use types, the metric may be biased against those areas with a high number of small establishments (e.g., "mom and pop" stores or the ubiquitous *bodega*). The challenge here derived from the format of the land use data (discussed above in Section VII.3.1); generally shopping centers and malls appeared in the real estate cadastre as a single activity. Counting this activity as equivalent to a *bodega* would be biased against the mall. Figure VII-18 shows this phenomenon, as the dissimilarity index scores highly, in part, in an area with few activity points, while scoring relatively low in a densely populated area with a not insignificant share of activities (likely corner store, *bodega*-type establishments).

**Figure VII-18. The Potential Bias of the Dissimilarity Index**



Note: The map on the left shows dwelling unit density at the block level while the points represent non-residential activities by four different activity types. The map on the right shows the grid-cell measured Dissimilarity Index, calculated based on land area according to equation (7.2). As can be seen, some areas with low dwelling unit density and a small number of activity points have high dissimilarity index (large shopping centers), while other areas with a high number of activities have fairly low dissimilarity indexes, partly a reflection of the small size of the relevant establishments.

Finally, in terms of the *density* of uses, we focus on residential uses, particularly dwelling units. Santiago has for a long time had fairly high recorded densities and gross, metropolitan-wide population densities, discussed above, show that the city remains relatively dense by this metric. At the micro scale, the densities, particularly among the poorest have been notorious. In the early 20<sup>th</sup> Century, for example, when earthquake

risks made multi-story buildings rare, residential densities in the working class *conventillos* still ranged from 500 persons to up to, perhaps, 1,200 persons per hectare, in *one-story dwelling* units (Matas & Balbontin, 1987; Hofer, 2003). While such extremely high population densities in single-story units no longer exist in Santiago, the lower income areas still exhibit high densities. We see the meso-level distribution in Figure VII-14; Figure VII-18 offers a glimpse of the phenomenon at the micro-level, showing very high dwelling unit densities, associated in part with the small block size still predominating in lower income areas.

#### VII.4 Exploring *Physical Neighborhoods*

As discussed in Chapter V, one approach to measuring the built environment for travel behavior analysis focuses on analyzing the influence of various independent measures, including ones similar to those presented in the previous Section. Another approach has been the explicit analysis of the neighborhood, as a whole, often in a “quasi-experimental” way. In this Section we aim to answer the basic question: can neighborhoods in Santiago be identified, “objectively,” based solely on measures of the local built environment?

**Table VII-3. Typologies of Santiago’s Residential Neighborhood Developments**

Neighborhood Type	Origins	Locations	Basic Traits
The Colonial City	Colonial roots, predominated through 19 <sup>th</sup> Century	Historical city center and immediate environs	Buildings with a continuous façade, quadrangular street grid
The Front Yard City	Upper class suburbanization at end of 19 <sup>th</sup> Century	Originally to the immediate east of CBD, predominant in most suburban development today	Attempts to “privatize space,” similar to U.S.-style subdivisions, cul-de-sac form, etc.
The Park City	Latter half of 20 <sup>th</sup> Century	Replacing original Front Yard City through lot consolidation & densification	Multi-story apartment buildings, for the most part densely placed, surrounded and linked by continuous greenspaces
The Marginal City	Lower income housing crises since city origins	Periphery (past and current)	Public housing projects, dense multi-story buildings, minimum attention to urban amenities and infrastructure
The “Renovated” City	Urban renovation subsidies aimed at center city re-development	Central city and surrounding areas identified as priorities for urban redevelopment by authorities	Multi-story apartment buildings, inserted into the traditional urban fabric

Source: Derived from Matas & Balbontin, 1987; except for the “renovated” city.

Past urban theorists (Matas and Balbontin, 1987) have suggested that at least four city types (cities within the city) can be identified in Santiago (see Table VII-3). Since the publication of that work, a fifth form has emerged, the “renovated city” spurred by the government’s development of urban revitalization subsidies as incentives to re-populate

the central city (see Section VII.1.1). Each of these city typologies has a fairly distinct mix of built environment characteristics; can, then, these city types be identified through a strictly built environment-based data analysis? The colonial city, for example, should display fairly dense characteristics with a strong grid predominance; the front yard city would have lower dwelling unit densities, a less grid-like street network, greater natural amenities and a lower mix of use; the park city would have high floor to area ratios, some mix of uses, a less quadrangular street network and some mix of uses; the marginal city would have a low mix of uses, extremely high dwelling unit density, with minimum amenities; and the “renovated city” might represent a hybrid of the park city and the colonial city. Do the data bear these hypotheses out? Can these typologies be derived strictly from “objective” data analysis?

Unfortunately various multivariate analytical approaches – including principal axis factoring, cluster analysis and principal components analysis (see, also, the Appendix) – applied to the grid cell-based data (only cells with at least 5% land area dedicated to residential uses were included) did not yield satisfactory results.<sup>135</sup> For example, principal components analysis, with oblique rotation (which allows for correlation among the resulting components), produced four components,<sup>136</sup> as seen in Table VII-4). These components do somewhat meet our expectations, as indicated by the variable loadings; furthermore the components labeled the “marginal city” and the “privileged city” show a fairly high negative correlation, as we would expect. Nonetheless, mapping these components in space produced no meaningful results. Furthermore, the principal components model, in rigor, is not the most appropriate theoretical model for this analysis.<sup>137</sup> Principal axis factoring proved no more useful in application, however.<sup>138</sup>

The results in Table VII-4 should be viewed tentatively, although they do, in part, reflect our intuition and expectations. Four principal components were extracted, representing 28%, 16%, 8%, and 7.6% of the variation in the 14 variables. The first component, essentially, represents the “marginal city,” with a strongly loading block morphology measure<sup>139</sup>, indicating the small, tight nature of these neighborhoods; an aspect that is correlated with both the intensity of 4-way intersections and, to a slightly lesser extent, 3-way intersections. This component also represents a large amount of road area (naturally, given the small block size) and dense development of housing units. Notably, other land uses do not load highly on this component. Components two and three, represent different aspects of non-residential uses, with component 2, “the productive city,” including manufacturing and office concentrations and component 3, “the provision city,”

---

<sup>135</sup> In strict rigor, since the purpose of the approach was to test the hypothesis that the different typologies in Table VII-3 were differentiable based on various built environment characteristics, confirmatory factor analysis, using structural equation modeling should be used (e.g., Everitt and Dunn, 2001).

<sup>136</sup> Using the “scree-plot” approach of extracting the number of components up to the point where the scree plot levels off.

<sup>137</sup> Basically, principal components analysis assumes unity in the diagonal of the matrix; in other words, the factors will explain all of the variance in each variable (there is no unique variance); see the Appendix.

<sup>138</sup> In principal axis factoring, there can be both common and unique variance, which seems more appropriate for the data here.

<sup>139</sup> Note, that the block morphology here is inverse to the original value presented in Figure VII-16; in other words, a larger value for AoverP in the grid cells corresponds with, generally, denser grid network.

representing commercial and social services. Not surprisingly, these two components are positively correlated (and also share the diversity index loading). Finally, component 4 represents the “privileged city,” with large average residential size and open space amenities.

**Table VII-4. Principal Component Analysis Pattern Matrix**

Variable	1	2	3	4
	“Marginal City”	“Productive City”	“Provision City”	“Privileged City”
Area over perimeter	0.93			
Road area	0.88			
Dwelling unit density	0.77			
4-way intersections per Km of roadway	0.73			
3-way intersections per Km of roadway	0.61			
Density of Plaza land	0.44			
Manufacturing distribution quotient		0.91		
Office distribution quotient		0.87		
Public health and social services distribution quotient			0.84	
Land Use Dissimilarity Index		0.32	0.70	
Commercial distribution quotient			0.62	
Density of Park land Area				0.78
Average residential size				0.69
Density of Outdoor Sports area				0.58
<b>Percent Variance Explained</b>	<b>28%</b>	<b>16%</b>	<b>8%</b>	<b>7.60%</b>

Notes: Distribution quotients calculated as relevant land use area/number of dwelling units. The variables included in the analysis were based on the variable’s Measure of Sampling Adequacy (MSA) from the anti-image matrix (only those variables with MSA higher than 0.5 were included in final analysis). Oblique (Promax) rotation was used, with the following component Correlation Matrix:

Component	1	2	3	4
1	1	-0.14643	-0.0913	-0.44395
2	-0.14643	1	0.349975	0.050266
3	-0.0913	0.349975	1	0.067258
4	-0.44395	0.050266	0.067258	1

The grid-cell analysis ultimately did not prove that the urban typologies outlined in Table VII-3 could be differentiated based on purely built environment-based characteristics alone. Of course, this does not mean that those typologies cannot be differentiated in such a manner. Perhaps other built environment variables, measured in another way via different spatial aggregation, would produce more meaningful results. Or, perhaps a different multivariate technique, such as confirmatory factor analysis utilizing structural equation modeling would produce better results. Or, perhaps the typologies represented in Table VII-3 exist in more subtle ways, not readily detectable by built environment

measures, requiring instead the more direct intermediation of our own perception and cognition. I leave the explorations of these possibilities for future research.

## VII.5 Conclusions

This Chapter has attempted to paint a portrait of Santiago's basic socioeconomic and physical structure and form. Since the early 20<sup>th</sup> Century, something of a planning tension between continental European approaches – characterized by some degree of compactness and densification – and “garden city” development via expansion – i.e., the typical North American-style suburbanization – can be detected. The ongoing need to house lower income groups continue to figure prominently in development pressures.

In terms of physical structure, broadly, we can see that Santiago's residential space is characterized by socioeconomic spatial segregation, although some slight decline in this segregation is apparent (consistent with the suggestion of Sabatini, 2000), and an increasing rate of urban expansion, particularly but not exclusively in the North. The city has a duo-centric business core, with the traditional CBD in the area of the *Plaza de Armas* now balanced with a new CBD (nearly equivalent in terms of office space), 4.5 kilometers east in the “El Golf” area of Las Condes/Providencia. Suburban office parks and increasing office development on the fringe associated with industrial decentralization is also apparent. Industrial development patterns come from environmental concerns forcing some industries out of the traditional urban core; locational competitiveness (space demands, modern facilities, major transport links) also fuel industrial relocations, which have contributed to the inner-city deindustrialization and subsequent brownfield issues. Commercial services also continue to expand outwards with suburbanization, including a notable number of large shopping centers (malls).

Residential dwelling characteristics largely match spatial income distribution patterns, with low income areas associated with high dwelling unit densities. The primary exception comes from the high densities of the large apartment buildings in the traditional and eastern CBDs and the “park city” apartments continuing to sprout up in the Eastern “cone of wealth.” The east also concentrates an important share of outdoor amenities, the primary exception being the center city parks and plazas, the latter which seems to play a role in somewhat equalizing public space distribution. The diversity index showed a heavy radial predominance, with large swaths of areas with low land use mix across the city. The historical grid pattern street still predominates, until one gets fairly distant from the center of the city, most notably in the far Eastern foothill suburbs.

While neighborhood typologies, characterized by distinct built environment metrics have been hypothesized for Santiago, the multivariate techniques employed here did not bear out those neighborhoods in a strict spatial sense. An interesting area for future research would be to further explore specific neighborhood identification on physical characteristics. For the analysis in Chapter X, I revert back to the TAZ as the spatial unit of analysis. But before looking at that analysis, let us, in the following Chapter, look briefly at the basic mobility characteristics of *Santiagoños*.

## VIII

### A METROPOLIS ON THE MOVE: SANTIAGO'S BASIC TRAVEL CHARACTERISTICS & IMPACTS

Having examined Santiago in the broader international and national contexts and having seen a basic representation of the city's built environment, we now look more closely at the travel behavior of the city's residents. This Chapter, drawing from the 1991 and 2001 household origin-destination surveys, provides a primarily descriptive overview of major travel characteristics and their evolution in time. It also derives a mobility throughput metric, based on passenger kilometers traveled. The Chapter ends with a brief discussion of some of the environmental and other impacts of Santiago's transportation system.

#### VIII.1 A Note on Data Sources

This Chapter draws primarily from data from the 1991 and 2001 household travel surveys carried out under the auspices of the Chilean National Transportation Planning Secretariat (SECTRA) (SECTRA, 1992b; SECTRA, 2002).<sup>140</sup> In both cases the surveys were carried out by the Catholic University of Chile, under the lead of Dr. Juan de Dios Ortúzar. SECTRA provided the survey datasets to this author.<sup>141</sup>

The 1991 survey included over 31,000 households (3% of the city's households at the time) interviewed during the work week (Tuesday-Thursday) of the "normal" (i.e., not summer) season.<sup>142</sup> The sample of households was randomly generated based on a cadastre of residential addresses. The survey covered the 34 *comunas* of Greater Santiago, which were broken down into 510 survey zones. Only trips greater than 200 meters and by persons over five years old were counted; the survey employed the trip evocation technique, whereby persons were asked about the previous day's trips. Expansion factors were developed based on the residential cadastre and correction factors were developed (to correct for family size, gender and age) based on census information (SECTRA, 1992a).<sup>143</sup> These factors allow use of the survey to approximate population characteristics.

The 2001 survey demonstrates advances in the state-of-the-art since the 1991 survey. While a smaller sample was used, all days of the week were included (including weekends) as was the summer season. Again, the survey was based on a randomly generated sample of households, with the sample frame constructed based on the urban lots database from the national tax authorities (Internal Tax Services, SII). Fifteen thousand households were included; 12,000 surveyed during the "normal season" and 3,000 during the summer time (in total, 1% of Greater Santiago's households). The

---

<sup>140</sup> For summaries of the survey results, see: SECTRA (1992a), Ortúzar et al (1993), and SECTRA (2004).

<sup>141</sup> I owe sincere gratitude to SECTRA for providing access to the data and related maps and other information; in particular, I thank Henry Malbrán Rojas, Alan Thomas, and Esteban Godoy for providing guidance to understanding the data and answering many questions regarding their use.

<sup>142</sup> April-June, 1991.

<sup>143</sup> The original correction factors were based on the 1982 Census; updated expansion factors, based on the 1992 Census, were provided to the author.

urban area considered was expanded from the 34 *comunas* of 1991 to 38 *comunas*, including those rapidly suburbanizing in the North and South (specifically, Calera de Tango, Pirque, Lampa, and Colina; see Figure VII-3). The area was broken down into 779 survey zones.<sup>144</sup> Other important differences relative to the 1991 survey include:

- consideration of all trips in the public space;
- including trips taken by all household members (regardless of age); and
- expansion of the number of trip purposes, from eight to 13.

In addition, the survey used travel logs, instead of the recall technique; with households advised prior to the actual date of the survey (SECTRA, 2004).<sup>145</sup> All of these changes certainly reduced the amount of under-reporting relative to the 1991 survey, particularly for discretionary travel. So, some caution is warranted in making comparisons with the 1991 data. Several control techniques were employed to minimize survey bias and error, including quality control of field staff and independent verification of coding (for more detail, see SECTRA, 2004; Ampt and Ortúzar, 2004).

The survey contains information on individual educational level, job status, household income (actual reported or estimated, not in income categories like the 1991 survey), 13 different trip purposes (e.g., work, errands, study), and 28 different travel modes (e.g., auto driver) or combination of modes (e.g., auto passenger-Metro). The household information is geo-coded at the center of the census block (nearly 50,000 blocks),<sup>146</sup> while the trip origin and destination information is geo-coded at the nearest street corner (or, sometimes, census block). The time of trip departure and arrival is also included.

While providing a wealth of useful information, the survey, as might be expected from such a large and detailed data set, does not come without errors or missing information. It is not always entirely clear where the errors come from. In some cases, they may come from incomplete data cleaning.<sup>147</sup> There is some indication that there may have been varying interpretations (either by the interviewer or interviewee) of trip purposes – for example, some reported travel times are extremely high, which suggests that the activity (e.g., leisure) may have been included in the trip.<sup>148</sup> Regarding trip distances derivable from the survey, 5092 trips (of 180,000 reported) had no distance (with at least one x,y coordinate missing); a total of 1703 households have at least one trip with no distance reported. Such data anomalies forced the exclusion of some trips and/or households from subsequent analyses; when relevant, these exclusions and/or modifications are reported.

---

<sup>144</sup> The OD survey zones range in size from 17 to 19,000 hectares, with an average of 250 hectares.

<sup>145</sup> Personal interviews were pre-scheduled; the surveyor visited the household two days before the established date to record general household information and deliver support materials.

<sup>146</sup> The census blocks range in size from 0.00097 to 4,000 hectares, with an average of 1.5 hectares.

<sup>147</sup> For example, it seems that a relatively large share of walk trips have strange time and/or distances reported; this may, in part, be due to the fact that authorities do not need to model walk trips and, as such, are not particularly concerned about their accuracy within the database.

<sup>148</sup> How, for example, would anyone characterize the destination of a trip that was a leisurely “window-shopping” trip that lasted for three hours and traveled only 1 kilometer?

## VIII.2 Basic Travel Characteristics

Fairly sustained economic growth over the past 15 years, together with changing demographics and land use patterns have contributed to notable changes in basic travel behavior and related influencing factors. Table VIII-1 presents a basic summary of changes in relevant characteristics.

**Table VIII-1. Evolution of Basic Socioeconomic & Travel Characteristics**

Category	Item	1977	1991	2001	AAGR (91-01)
<i>Socioeconomics</i>	Avg. HH Income (US\$ 2001)	n.a.	\$4,700	\$9,000	6.5%
<i>Demographics &amp; Motorization</i>	Households	649,820	1,162,845	1,484,903	2.4%
	Persons	3,483,084	4,502,099	5,325,193	1.7%
	Auto Fleet	208,263	414,798	748,007	5.9%
	Motorcycle Fleet	n.a.	6,621	17,639	9.8%
	Bicycle Fleet	n.a.	79,983	1,215,592	27.2%
	Residents per HH	5.36	3.87	3.59	-0.8%
	Vehicles per 1000 Persons	59.9	93.6	140	4.2%
	Vehicles per HH	0.32	0.36	0.50	3.5%
	Drivers License per 1000 Pers	n.a.	170	254	4%
Drivers License per HH	n.a.	.66	.99	4%	
<i>Trip Making</i>	Trips per Person	1.04	1.69	2.39	3.5%
	Trips Per HH	5.56	6.54	8.89	3.1%
	Work Share All Trips	n.a.	39%	27%	-3.7%
	School Share All Trips	n.a.	28%	19%	-3.5%
	"Other" Share All Trips	n.a.	1.3%	22%	28%
	Shopping Share All Trips	n.a.	6.5%	13%	6.9%
<i>Aggregate Mode Share Evolution</i>	Private Transport Mode Share	11.6	19.7	39	6.8%
	Public Transport Mode Share	83.4	70.5	51.8	-3.1%
	Other	5	9.8	9.3	-0.5%
<i>Disaggregate Mode Share Evolution</i>	Auto	9.8	14.7	27.4	6.2%
	Bus	66.4	47.1	30.4	-4.4%
	Metro	3.3	6.7	5	-2.9%
	Walk	16.4	21.1	26.6	2.3%
	Taxi	n.a.	2.8	4.1	3.8%
	Other	4.2	7.7	6.5	-1.7%

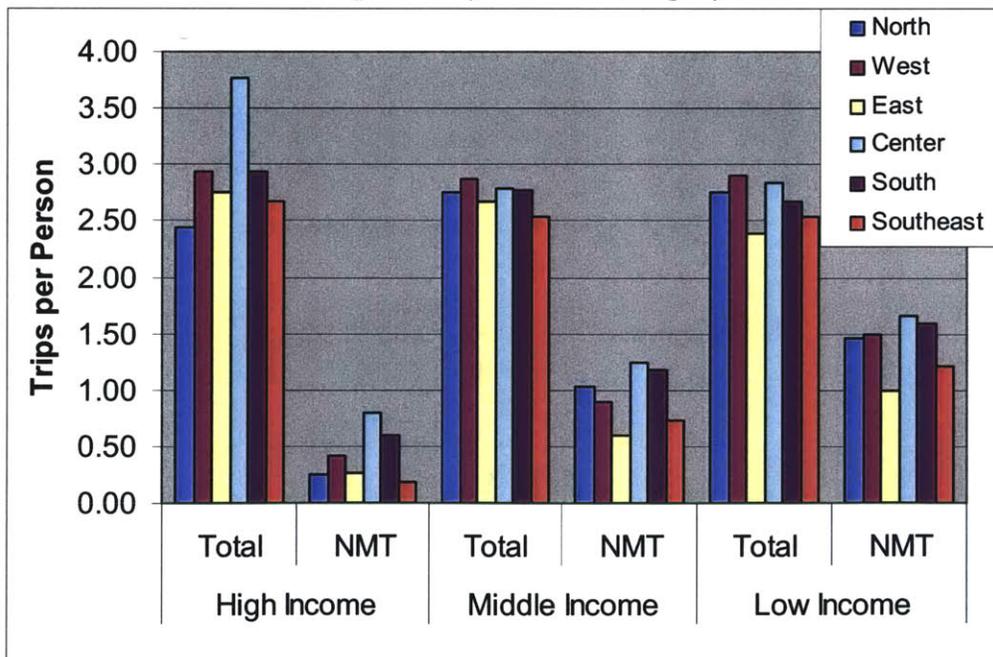
Sources: SECTRA, 1992a,b; 2002; 2004. Notes: Only data for the 34 *comunas* common to the 1991 and 2001 surveys are used. Travel information is for comparable observations (i.e., trips over 200 m, by individuals over five years old) for normal work week. Auto includes drivers and passengers; Metro includes combinations; Taxi includes Collective (shared) taxis. It appears as though the 1991 survey only included "utilitarian" bicycles, as it is unlikely the bike fleet grew so much in the 10 years.

Note, that the data compared across the time periods are made as comparable as possible. This means that the data for 2001 cover only the same geographic area as the 1991 data (i.e., 34 *comunas*); furthermore the trip data reflect only comparable trips (i.e., “normal season” workday, trips over 200 meters by persons over five years old). Among the noteworthy trends: the large increase in the auto fleet, in absolute numbers and in per capita and per household terms; the growth in the person trip rate; the considerable growth in the share of discretionary (non-work, non-school) travel, not only shopping trips, but most significantly other trip purposes; and, the growth in auto mode share, coming at the apparent expense of public transport mode share, both bus and Metro.

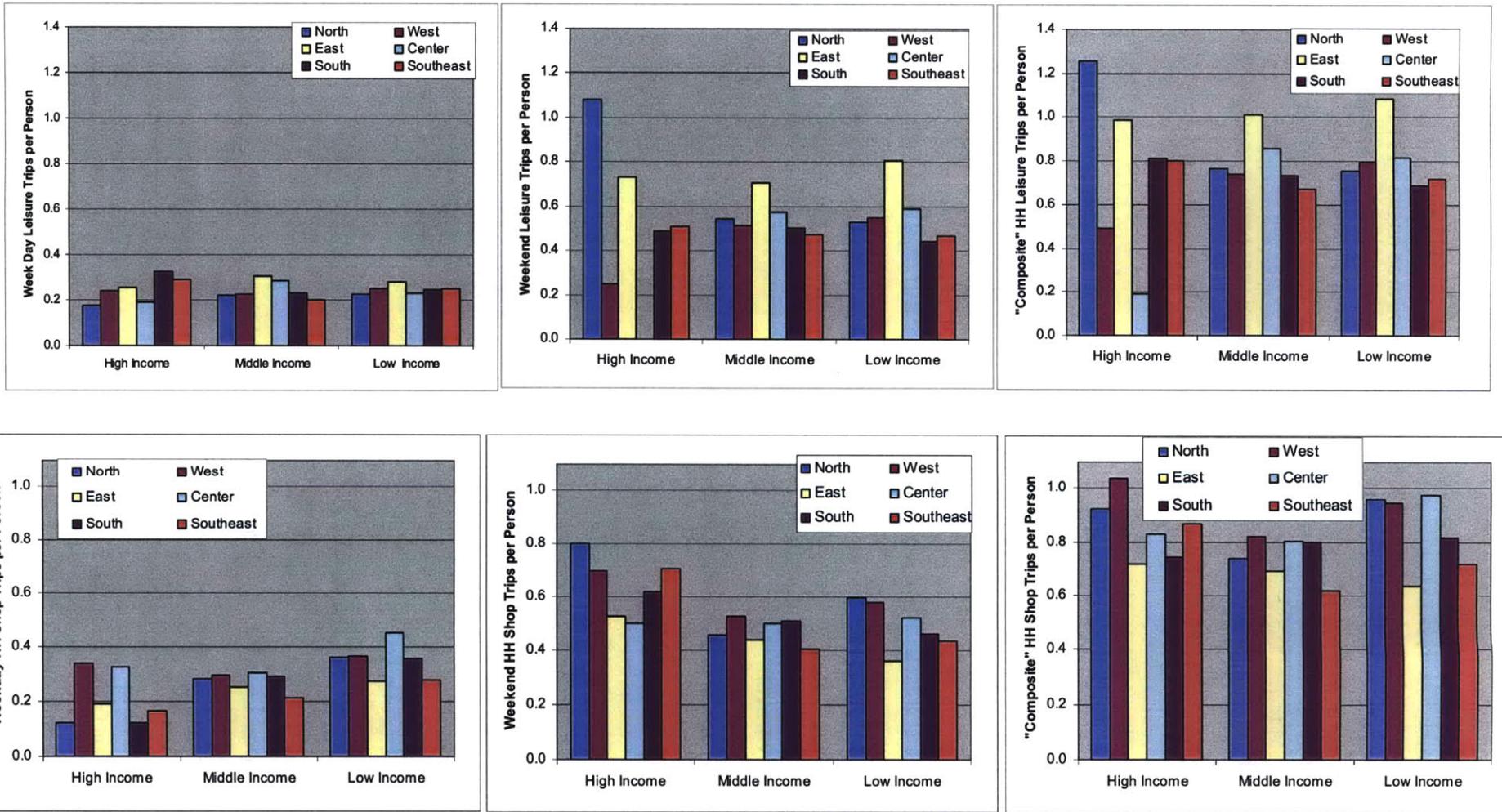
### VIII.2.1 Trip Rates & Purposes

While some of the changes can be attributed to improved survey methodology, the survey data from 1991 and 2001 show a clear increase in discretionary travel. While the trip rate for school and work has remained nearly the same, the total trip rate has increased, as we would expect with a growth in income (see, e.g., Schafer, 2000). Across the city, in 2001, the aggregate data reveal an average trip rate of 2.8 trips per person per day; a rate which exhibits surprising constancy across income groups (when non-motorized trips are included) and, in general, across different parts of the city (see Figure VIII-1). Generally, weekends display lower trip rates; however, as we would expect, weekends account for a large share of non-work, non-school travel as evidenced, for example, by the high relative trip rate for shopping and leisure travel (recreation, social, eating/drinking) on these days (see Figure VIII-2). This points to an important need to examine travel on all days when looking at discretionary travel.

**Figure VIII-1. Work Week Trip Rate by Income Category and Sector of the City<sup>149</sup>**



<sup>149</sup> Based on survey expansion factors; the higher trip rate for high income residents of the center city might be partly attributable to survey bias. The trip rates here differ than those from Table VIII-1, since the rates shown here include all trips, while those from Table VIII-1 are made comparable with the 1991 data.



**Figure VIII-2. Leisure and Shopping Trip Rates: Weekday, Weekends and “Composite” Household<sup>150</sup>**

<sup>150</sup> Note that the trip rates are not for the same observed household; the rates are based on those households in the relevant sector of the city and relevant income category for the relevant day of the week. As such, the “composite” figures represent the average total value, derived from aggregating different households matched according to income and location. The very low level of leisure trips for high income households on weekends could be attributed to actual behavioral differences, but might also be due to the possibility that, for example, high income households living in the city center may actually not be at home to be surveyed because of, perhaps, a propensity of these households to leave the city for the weekend.

We would expect a fair amount of household travel, particularly discretionary travel on the weekends and during the summer, to be comprised of trips beyond the metropolitan area. The relevance of this information to the idea of sustainable mobility comes from the potential substitution between intra-urban and inter-urban travel and the fact that reduced intra-urban travel may be compensated for by increased inter-urban travel (with important implications for some impacts, such as greenhouse gas emissions). Considering all external trips (from trips to just outside the study area to trips to other parts of the country), the data reveal that such travel accounts for anywhere from 0.3% to over 1% of all trips, with an important increase on both the weekends and during the summertime (see Table VIII-2).<sup>151</sup> Recreation and other trip purposes account for important shares of a given day's external trips on all days, but particularly on weekends.

**Table VIII-2. Trips with Origins or Destinations Outside the Metropolitan Area: by Primary Purpose and by Season**<sup>152</sup>

Purpose	Trip Purpose as Share of All External Trips			
	Normal Work Day	Saturday	Sunday	Summer Week Day
Accompany	0%	2%	1%	10%
To Work	34%	11%	2%	21%
Religion	1%	8%	1%	0%
Other	17%	23%	26%	24%
For Work	16%	5%	1%	16%
Recreation	16%	45%	42%	20%
Visit	6%	6%	19%	5%
External Trips as Share of All Trips	0.30%	0.60%	1.10%	1.10%

### VIII.2.2 Average Travel Times and Distances

Looking again at comparable data across the 1991 and 2001 surveys, we see a slight improvement in *reported* travel times. For a normal work day in 1991, the average trip time was approximately 38 minutes; for comparable trips in 2001, the average trip time *declined* slightly to 35 minutes. Here, then, we see the countervailing forces implied by the increased automobility of the population. While the increasing use of autos certainly leads to a more congested network and slower travel speeds, the increased general speed of the auto relative to the bus plays some role in reducing individual travel times.

Interestingly, there is a mix of travel time increases and decreases across modes, although we need to view these *reported* times with some caution.<sup>153</sup> Nonetheless, the fairly stable times in light of increasing travel demand does indicate some maintenance of overall

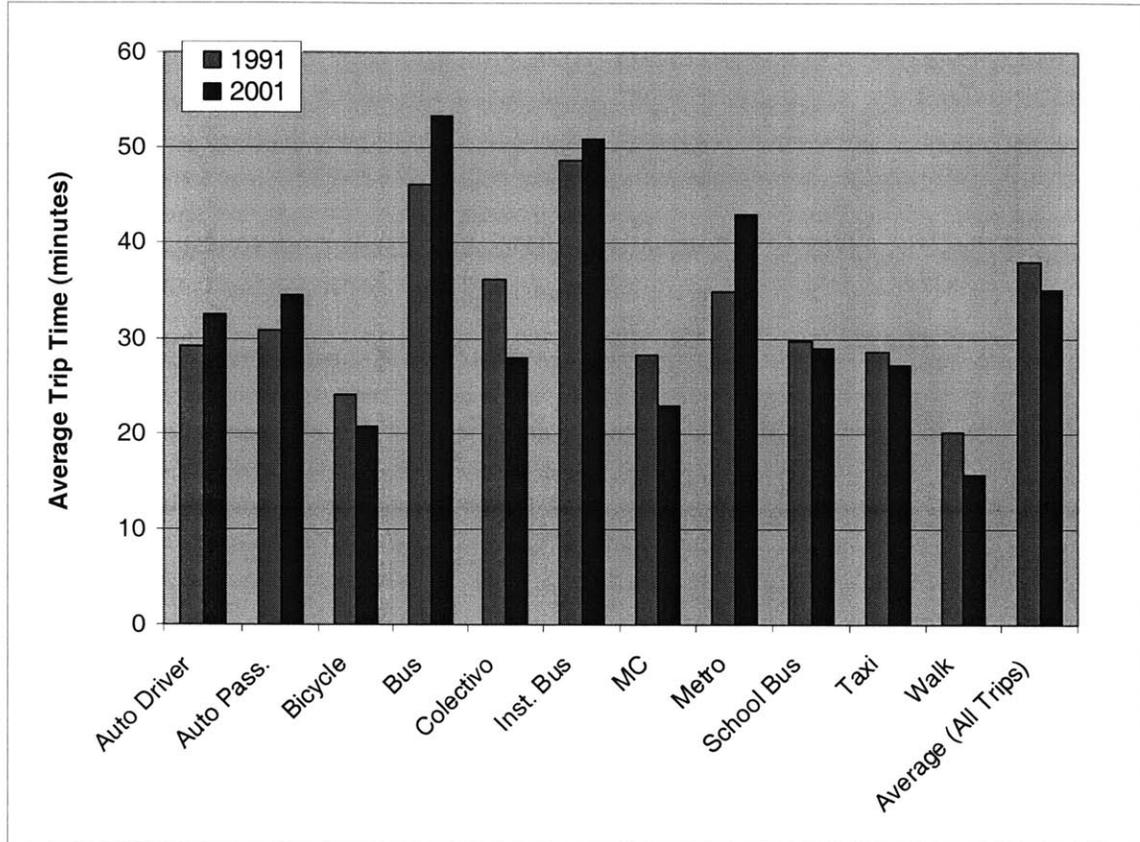
<sup>151</sup> Note the potential for under-reporting of these trips since many households making such trips may likely be under-represented in the sample.

<sup>152</sup> Only the trip purposes that account for a share of all external trips of greater than 5% on at least one of the relevant days were included in this table.

<sup>153</sup> They are subject to reporting & recording error, differences in perceptions of time (and time burden), etc.

accessibility. Some of the improvement can likely be attributed to improved system management (e.g., of the bus system, traffic signalization, etc.), infrastructure improvements, and possibly changes in location patterns and destination choice flexibility. The slight increase in Metro time (if not due to reporting anomalies) could be due to the addition of Line 5 which reaches into the suburbs in the South.

**Figure VIII-3. Average Reported Weekday Travel Times By Mode: 1991 vs. 2001<sup>154</sup>**



Sources: Derived from SECTRA, 1992b, 2002.

Including all weekday trips, a *Santiagoño*, on average, travels 31 minutes per trip, with an average trip distance of 5 kilometers. At a trip rate close to three trips per person, the average *Santiagoño* travels for 1.4 hours per day – on the high end of the range of average daily travel times reported for other places around the world (e.g., Schafer, 2000).<sup>155</sup> Some variation in times, distances and trip rates can be detected based on day of the week and season (see Table VIII-3).

<sup>154</sup> The Metro times include those for all multi-modal trips (e.g., bus-metro, auto-metro, etc.).

<sup>155</sup> SECTRA (2004) reports an average time from the survey of 27 minutes, four minutes lower than the figure I derived. This difference could be due to use of the updated expansion factors used here and/or the fact that for this analysis several travel time outliers and/or other anomalies were corrected (e.g., trips with very strange results – such as extremely small travel times reported for very long trips – and apparent calculation errors based on trips departing late on one day and arriving early on the next day).

As we might expect, considerable variation exists across income categories. In short, the higher income groups tend to travel further and faster. The low mobility range of the poorest is reflected in their low overall average travel distances and times, product in part from their heavy dependence on walking (accounting for 48% and 55% of the two lowest income categories' trips; see Table VIII-4). Weekends and summertime reveal the same general patterns.

**Table VIII-3. Average Trip Times, Rates and Distances**

	Average Trip Time (minutes)	Trips per Person	Average Trip Distance (kilometers)	Total Travel Time Per Person (minutes)	Total Travel Distance per Person (kilometers)
Weekday	31	2.8	5.0	86	14.0
Saturday	31	2.6	4.7	80	12.2
Sunday	28	2.4	4.4	67	10.6
Summer Weekday	36	2.1	5.5	75	11.6
Summer Saturday	31	2.1	5.0	65	10.5
Summer Sunday	32	1.9	4.7	60	8.9

**Table VIII-4. Travel Times, Distances and Modes by Income Strata: Work Day<sup>156</sup>**

Avg. HH Income (US\$)	Avg. Trip Dist.	Avg. Trip Time	Mode Share							
			Auto	Bus	Taxi	Colec-tivo	Metro	Walk	Bike	Other
109,059	5.58	19.66	69%	1%	0%	0%	4%	23%	0%	3%
42,280	5.75	29.81	69%	8%	3%	0%	6%	9%	0%	4%
13,200	5.55	31.86	34%	25%	2%	2%	7%	25%	1%	4%
6,131	5.19	33.31	17%	31%	1%	3%	4%	37%	2%	4%
3,542	4.49	30.67	10%	30%	1%	3%	2%	48%	3%	4%
1,492	3.69	26.54	7%	27%	1%	3%	1%	55%	2%	3%

Note: The second highest income category records a walk share considerably lower than all other income categories; analysis of these households revealed nothing obviously different, absent their overwhelming spatial concentration in the "cone of wealth."

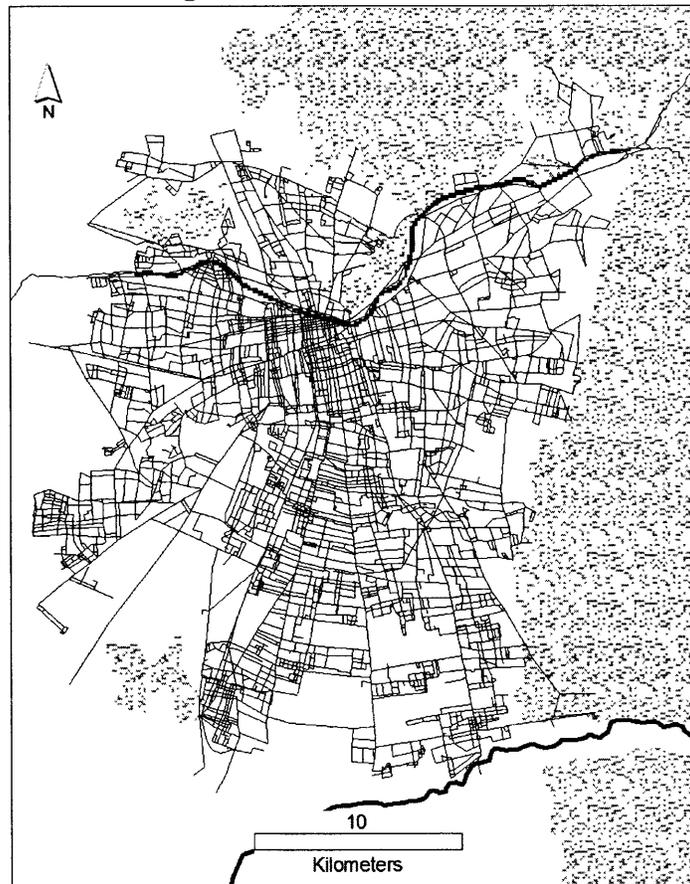
<sup>156</sup> This table excludes trips with no distance reported. Without this exclusion, there is no major change in times or mode shares:

HH Inc. Srata	Avg. Time	Auto	Bus	Taxi	Colec.	Metro	Walk	Bike	Oth.
109,059	19.9	71%	1%	0%	0%	3%	22%	0%	3%
42,280	29.9	69%	8%	3%	0%	6%	9%	0%	4%
13,200	32.0	35%	25%	2%	2%	7%	25%	1%	4%
6,131	33.4	17%	31%	1%	3%	4%	37%	2%	4%
3,542	30.7	11%	30%	1%	3%	2%	47%	3%	4%
1,492	26.6	7%	28%	1%	3%	1%	55%	2%	3%

### VIII.2.3 Mode Shares

As seen in Table VIII-1, relative auto use increased at a rapid pace between 1991 and 2001, virtually identical in rate to motorization (6.8% and 7% per year growth rates, respectively). We can also see a concomitant decline in public transport mode share, although in total by only half the rate of auto use increase; this result indicates that auto use is increasing total mobility – eating away at public transport mode share, but also inducing new travel, on average. Total trips by both bus and Metro continue to increase, but at a rate slower than population growth. An interesting result of the comparison across time is the consistent increase in the share of walking trips. Some of this may derive from survey methodology differences; but this could also result from other social and behavioral changes (increased comfort in public spaces), some of which might even be attributable to changes in built environment.

**Figure VIII-4. Greater Santiago's Intra-urban Bus Routes (1999)**



Source: Provided by SECTRA

Regarding the primary public transport modes, Santiago in 2001 still enjoyed remarkably ubiquitous bus service, with the possibility to go from nearly anywhere to anywhere by bus (see Figure VIII-4). In terms of the Metro, coverage is obviously more limited; not an insignificant fact, given the fact that for most periods of the day walking is the primary means of Metro access and egress (Table VIII-5). Perhaps not surprisingly, then, we can see considerable spatial variation in Metro line ridership across the city, with an apparent

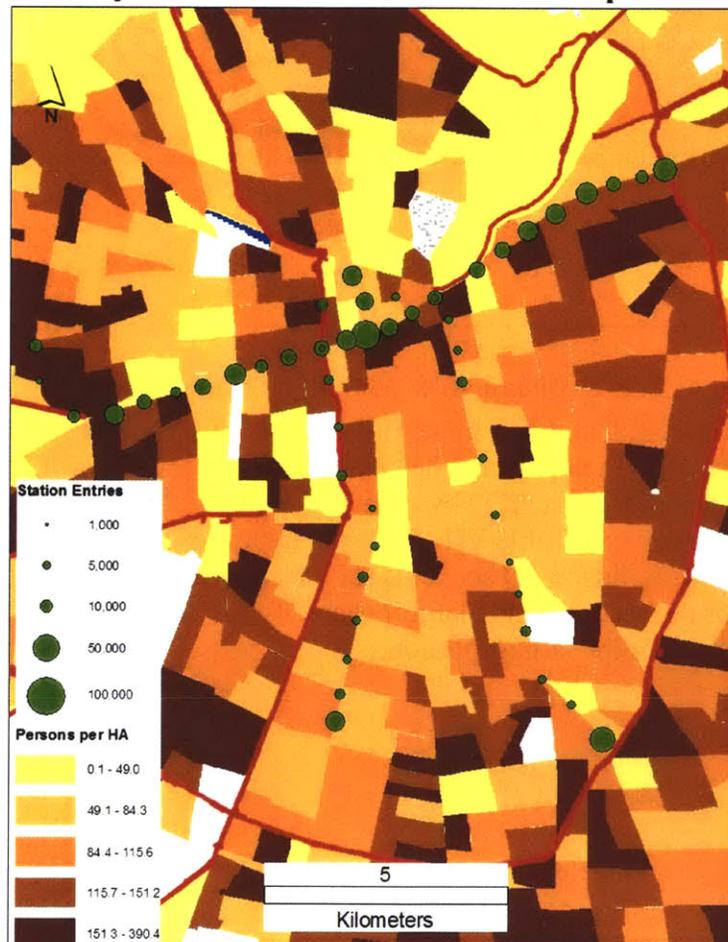
correlation between population density and Metro station accesses (see Figure VIII-5). With the exception of the stations on the Eastern end of Line 1, that record low ridership despite their high density location (this is a lower income area), and the two Southern terminal stations, with fairly high ridership despite low densities (these stations serve the highly populated Southern suburbs), we can see, otherwise, a strong relationship between station utilization and population densities.

**Table VIII-5. Metro: Primary Mode of Access/Egress (2001)**

Mode		8 – 9 am	11 am – noon	1 – 2 pm	4 – 5 pm	6 – 7 pm	9 – 10 pm
Access	Walk	39%	71%	77%	79%	83%	84%
	Bus	22%	14%	11%	10%	7%	6%
	Colectivo	14%	4%	3%	3%	2%	2%
Egress	Walk	88%	86%	81%	77%	64%	53%
	Bus	5%	7%	9%	10%	12%	13%
	Colectivo	2%	3%	3%	4%	10%	17%

Note: Bus does not include Metrobus. Source: Metro, 2001.

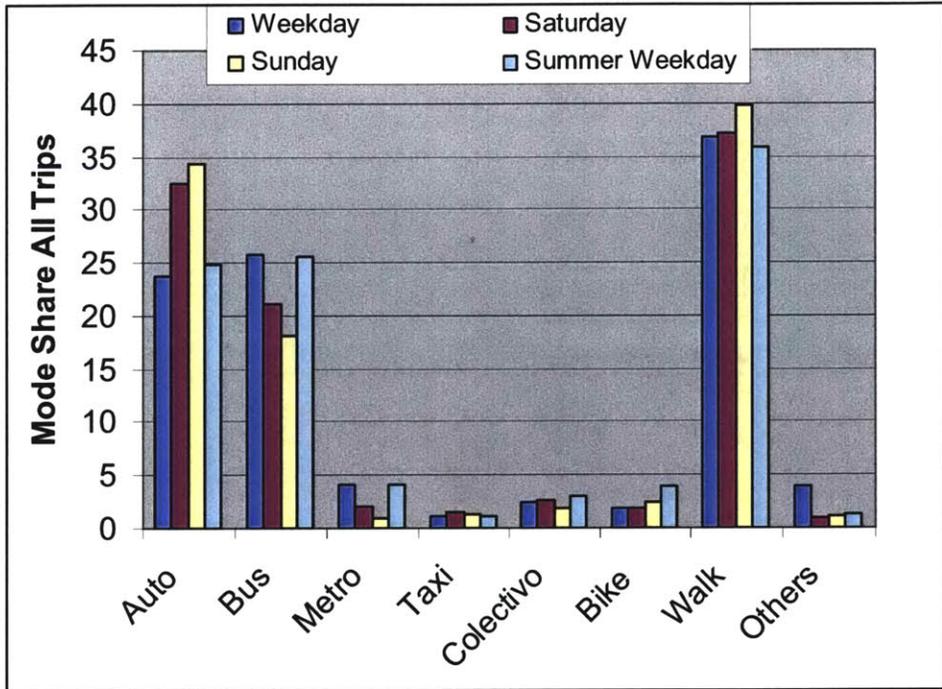
**Figure VIII-5. Weekday Metro Station Accesses & TAZ-Population Densities**



Source: Station accesses from Metro, 2001.

Looking at variation in mode shares according to weekday versus weekends and also including summer weekdays (see Figure VIII-6), we see that walking predominates irrespective of the day. Bus travel accounts for the second highest share on weekdays (including in the summer), but auto (including passengers) accounts for the second highest mode share on Saturdays and Sunday. There is a notable increase in summer bike mode share (and a slight increase on Sundays) and a notable decrease in weekend Metro use.

**Figure VIII-6. Mode Share for All Trips. Variation by Season and Weekday/Weekend**



**VIII.2.4 Total Travel Distances & Mobility Throughput**

We saw in Table VIII-3, that the average travel distance in Santiago is on the order of five kilometers per trip. In aggregate, the city recorded on the order of 26 million passenger kilometers of travel (PKT) by all modes in 2001, the largest share by bus followed by automobile (see Table VIII-6). Work travel accounts for almost 40% of annual PKT and of that, bus travel accounts for the majority share. Significantly, leisure travel accounts for the second single largest share of PKT, 15% (almost 4 million PKTs), with auto accounting for the largest portion.

**Table VIII-6. Total Annual Passenger Kilometers Traveled (PKT) (in millions) by Different Modes**

Mode	Purpose							Total PKT	Share All PKT	Weighted PKT	Share Weighted PKT
	Errand	Health	Leisure	Other	Shopping	Study	Work				
<i>Auto</i>	1,614.7	122.1	1,677.8	1,095.1	822.1	498.8	2,642.9	8,473.4	32.7%	49,843.8	40.5%
<i>Bicycle</i>	35.9	0.6	59.8	16.7	24.7	6.7	138.0	282.5	1.1%	338.9	0.3%
<i>Bus</i>	1,204.7	366.6	1,507.5	1,175.0	868.0	1,387.8	5,253.5	11,763.2	45.5%	52,280.9	42.4%
<i>Colectivo</i>	83.4	30.5	59.2	81.7	89.0	23.3	121.8	488.8	1.9%	2,444.0	2.0%
<i>Metro</i>	151.3	24.1	58.5	30.0	67.1	97.5	220.3	648.8	2.5%	3,027.6	2.5%
<i>Other</i>	49.7	16.6	121.7	70.3	23.1	311.6	557.7	1,150.7	4.4%	6,768.8	5.5%
<i>Private-Metro</i>	8.3	6.2	5.4	4.4	2.5	14.4	73.6	114.8	0.4%	605.5	0.5%
<i>Public-Metro</i>	88.3	45.7	59.6	58.0	20.4	175.3	524.3	971.7	3.8%	4,426.7	3.6%
<i>Taxi</i>	41.9	17.3	62.4	47.4	33.3	43.7	52.2	298.3	1.2%	1,754.6	1.4%
<i>Walk</i>	231.3	32.3	344.0	218.2	505.1	213.9	136.8	1,681.6	6.5%	1,681.6	1.4%
Total PKT	3,509.4	662.0	3,956.0	2,796.8	2,455.4	2,773.0	9,721.1	25,873.8	100.0%	123,172.5	100.0%
Share all PKT	14%	3%	15%	11%	9%	11%	38%	100%			
Weighted	17,235	3,086	18,938	13,430	10,425	12,860	47,199	123,173			
Percent Weighted	14%	3%	15%	11%	8%	10%	38%	100%			

Notes: The total values are calculated by expanding the amount traveled on a given day (i.e., normal weekday, normal Saturday, normal Sunday, summer weekday, summer Saturday, summer Sunday) in the survey by the relevant survey expansion factor. The totals for each representative day were then expanded based on relevant composition of the year. Private-Metro refers to Private mode (auto) combinations with the Metro, Public-Metro refers to Bus-Metro combinations. The weighted PKT represents a weighting measure that, literally, weights PKT by each mode relative to the mode's physical weight and adjusting for average occupancy levels; all the other modes are indexed to walk, which *ceteris paribus*, is inarguably the most sustainable form of travel. This metric serves as a rough proxy for total mobility throughput (i.e., drain on capital stocks; see Chapter 3). This basic weighting scheme is entirely flexible and could be made to vary by time of day, vehicle technologies, occupancy levels, etc. For the Metro combinations (public-Metro, private-Metro), the weight is derived by dividing evenly between the two relevant combination modes (auto and bus). The mode "Other" is given the auto weight. The weights are derived as follows:

Mode	Actual Avg Weight (lbs.)	Walk-Indexed Weight	Occupancy	Occupancy-Adjusted Weight
Walk	150	1	1	1
Bike (+person)	180	1.2	1	1.2
Car	1500	10	1.5	6.7
Bus	20000	133	30	4.4
Metro	49000	327	70	4.7

As described in Chapter 3 (**add Section number**), the two critical aspects comprising sustainable mobility are the personal benefit derived (accessibility) relative to the capital drain incurred. In other words, a *more* sustainable mobility system is one that provides more accessibility per unit of mobility. Of course, the negative impacts related to mobility will depend on the technologies used. For the purposes of illustration, in this case we have derived a simple weighted PKT measure to proxy for relative impact (capital drain); the weight, quite simply, reflects the vehicle weight (relative to walking) and average occupancy levels (see the details in the note to Table VIII-6). Based on this admittedly crude weighting scheme (one which would could and should be extended upon to reflect the relative importance of relevant impacts, such as local air pollution, as well as variation by time of day, etc.), we see that bus and auto travel account for the overwhelming share of proxied impact. The weighting scheme has little effect (compared to unweighted PKT) on the relative mobility throughput estimated effects according to trip purpose.

### VIII.3 Transportation’s Environmental and Other Effects

Ideally, the weighted throughput metric presented in the previous section would reflect the full extent of the relevant impacts. Such impacts would include air pollution, relative congestion effects, accidents, land utilization, among others. Fully characterizing the extent of those effects extends beyond the scope of this research; detailed explorations can be found in, for example, Zegras and Litman (1997); Zegras (1998a); and Lanfranco et al (2003).

Of negative effects, perhaps most notoriously Santiago suffers serious air pollution problems, including from high concentrations of total suspended particulates (TSP), respirable particulates (PM<sub>10</sub>), ozone (O<sub>3</sub>), and carbon monoxide (CO). The transportation sector accounts for 56% of PM<sub>10</sub> and 87% of NO<sub>x</sub>, a precursor to ozone (transport is responsible for 31% of VOCs, the other ozone precursor) (see Table VIII-7) – the two most serious problems of air pollution in the capital city.

**Table VIII-7. Annual Pollutant Emissions Inventory by Source (% of Total): 2000**

Source	PM10	CO	NOx	VOCs	SO2	NH3
Buses	27.6%	3.2%	37.9%	3.1%	8.8%	0.0%
Trucks	18.5%	1.8%	17.1%	3.0%	5.2%	0.0%
Light Duty Vehicles	9.3%	87.9%	30.7%	24.5%	10.2%	3.1%
Off-Road Vehicles	1.0%	0.8%	1.6%	0.3%	0.1%	0.0%
<i>Mobile Sources Total</i>	<i>56.4%</i>	<i>93.8%</i>	<i>87.3%</i>	<i>30.9%</i>	<i>24.3%</i>	<i>3.2%</i>
Point & Area Sources	43.6%	6.2%	12.7%	69.1%	75.7%	96.8%

Source: CONAMA, 2003.

In the past decade, authorities have focused on reducing transportation air pollutant emissions primarily by improving fuel quality and strengthening vehicle emission standards, but also through the use of several system management measures put into place during periods of severe pollution risk (e.g., Díaz, 2004). In combination with interventions in fixed sources, the efforts have produced important improvements in pollutant concentrations as exhibited by declines in severe pollution days. For example,

since implementation of the pollution control plan of 1997, the city has experienced a 18-34% drop in average winter time PM<sub>10</sub> concentrations measured at seven monitoring sites across the city (the city suffers from a thermal inversion in the winter months). Ozone concentrations have proven to be more tenacious, with the number of days exceeding the norm staying relatively constant (40-46 per year) over the past six years (CONAMA, 2003).

While it has not been thoroughly studied since the late 1980s, transportation noise pollution, particularly along major travel corridors certainly poses major acute effects (see, e.g., Intendencia, 1989; Santana, 1995). In this case, the contribution of heavy vehicles, particularly buses cannot be ignored. In terms of accidents, over the seven year period from 1994 to 2001, the total number of *reported* incidents increased by approximately 3.7% per year (compared to a growth rate in the private motor vehicle fleet of 7%); not only has the number of incidents per vehicle declined,<sup>157</sup> but the gravity of the incidents' effects has as well (see Table VIII-8). The rate of death and injury per incident has also declined, which may reflect improved system management, improved vehicle safety standards, user practices (e.g., use of seatbelts), among other factors.

**Table VIII-8. Reported Traffic Incidents and Deaths and Injuries in Santiago**

Category			Per Vehicle		Per Incident	
	1994	2001	1994	2001	1994	2001
Incidents	19,378	25,171	0.04	0.03	n.a.	n.a.
Deaths	394	340	0.0008	0.0004	0.020	0.014
Severe Injury	3,130	2,659	0.01	0.00	0.162	0.106
Less Severe Injury	3,124	2,713	0.01	0.00	0.161	0.108
Light Injury	9,752	12,361	0.02	0.02	0.503	0.491
Total Injuries	16,006	17,733	0.03	0.02	0.826	0.705

Sources: 1994 from Zegras (1997); 2001 from data provided to the author by the Comisión Nacional para la Seguridad de Tránsito (2004). Note: the per vehicle rate is calculated based on the total private motor vehicle fleet in the 34 Comunas of Greater Santiago; this simply aims to show accidents relative to gross city-wide motorization levels.

The apparent relative improvement in transportation-related air pollution and traffic safety in Santiago suggests the city will follow the trends exhibited in most of the industrialized world: with increased income growth, at least some negative effects of motorization and motor vehicle use can be ameliorated by technological and management interventions. Whether the effects can be fully contained within acceptable limits (however those limits are ultimately determined) will depend on growth in demand, further technological improvements, rate of adaptation of new technology and ongoing system management and behavioral changes (particularly for accidents). Whether other, longer-term sustainability impacts can also be effectively managed remains to be seen. For example, Heywood et al (2003) looking at the private motor vehicle fleet evolution possibilities in the U.S. and its implications for fuel consumption (and, thereby, greenhouse gas emissions), estimate that fairly aggressive technological development and

<sup>157</sup> Note that data for 2003 indicate a total decline in incidents relative to 2001; the 2001 data were used to be consistent with the travel survey data year.

market penetration – together with *no net growth* in vehicle kilometers traveled – would be required for the United States to reduce its personal transportation energy consumption to 1970 levels by the year 2030.<sup>158</sup> For Chile, which admittedly accounts for a minor fraction of global greenhouse gas emissions, climate change impacts could be severe (e.g., Browne, et al., 2005). Nonetheless, Santiago’s per capita private vehicle use would have to increase by a factor of 8 to 10 before it reached current per capita usage levels in U.S. cities. Ultimately, the longest term sustainability impacts may come from the loss of open space, parks and other natural patrimony – those factors directly related to patterns of urban growth.

Incorporating the broad transportation effects into a more rigorous and valid mobility throughput metric must ultimately be accomplished through thorough local inputs and clearly reflect relative local priorities, appropriate discount rates, etc. Furthermore, for the ultimate purposes of forecasting, the metric must be able to adapt to expected changes in time (such as evolution in vehicular technologies). As mentioned, the “weight” proxy proposed above can be fairly easily adapted to reflect actual local conditions.

#### **VIII.4 Conclusions**

The data reviewed in this Chapter reveal that, over the past decade, Santiago’s strong economic growth and emerging middle class has translated, as we would expect, into rapid growth in motorization rates (private vehicles per person), trip rates, and discretionary travel as a share of all travel. For discretionary travel, the weekends account for a large portion of relevant (e.g., leisure and shopping) trips. External trips still make up, apparently, a small share of total household travel. The data further reveal, again as we might expect, a gain in auto mode share, at the expense of public transportation. Across both income groups and areas of the city, trip rates (trips per person) are comparable, with non-motorized travel making up an important share of low income trips. Overall, walking predominates, accounting for over one-third of all trips on weekdays and weekends; auto and bus provide for nearly an equal share of weekday trips (roughly 25 percent each), with auto mode share increasing notably on the weekends.

Average travel times (as reported in the survey) have changed very little over the past decade; on a weekday, the average *Santiaguino* travels a total of almost 1.5 hours per day. The average distance per trip is about 5 kilometers, reflecting Santiago’s still fairly compact form. Consistent with expectations, the highest income groups travel – on average – the furthest, the fastest. As for passenger kilometers traveled (PKT) – i.e., mobility throughput – auto and bus dominate, as do work trips which account for almost 40% of annual PKT; the next largest share is leisure travel (recreation, social and eating/drinking), accounting for 15% of annual PKT. Both transportation-related air pollution and traffic safety conditions appear to be improving (the latter in terms of incidents per vehicle, anyway); it is unclear how longer term sustainability issues related

---

<sup>158</sup> A scenario of lower annual growth in new vehicle sales, a decline in light duty truck market share, a 50 percent market share of hybrid vehicles, and *no growth* in VKT would result in: a 13 percent increase in fuel consumption between 2000 and 2010; a return to 2000 levels by 2020; and a reduction to 1970 levels by 2030.

to greenhouse gas emissions and land conversion might be impacted under current trends in travel demand growth.

## IX

### PULLING THE PIECES TOGETHER: THE BUILT ENVIRONMENT & SUSTAINABLE MOBILITY

The previous three Chapters: (1) situated Santiago in an international context, which revealed that the city still has a fairly low motorization rate (even relative to its income peers), yet a fairly high trip rate; (2) sketched the principal meso and micro-level characteristics of Santiago's built environment, suggesting a fairly compact city form and a duo-centricity; and (3) reviewed the major patterns and trends in personal mobility in the city and their impacts. Drawing from this background, and building from the theoretical sustainable mobility framework developed in Chapters II and III and the literature on the built environment and travel behavior reviewed in Chapter IV, this Chapter aims to answer several questions, specifically:

- What role might the city's built environment play on personal travel behavior?
- And furthermore, what might be the influence of built environment on *sustainable urban mobility*?

To answer these questions, the Chapter first provides a short review of previous analyses for Santiago. Following that, the Chapter presents several models examining different relevant aspects of household and individual travel behavior. First, since household vehicle use begins with vehicle ownership, a model exploring the various factors – including the built environment<sup>159</sup> – influencing vehicle ownership is estimated. This model links directly to a model of household motor vehicle use, in which again the role of the built environment is explored. Then, models of mode choice and destination choice are estimated, with the goal of deriving utility-based accessibility measures, as introduced in Chapter 3. Using these accessibility measures, and estimates of related mobility throughput, I then offer preliminary answers to the question “what influence does the built environment have on sustainable mobility?”

#### IX.1 Precedents

For the case of Santiago, several relevant analyses into the influence of urban form on travel behavior exist. Kain and Liu (2002), in a series of regression formulations on Municipality-aggregated data in Greater Santiago, find little evidence to support the role of population density in determining public transport mode share.<sup>160</sup> At a similar, aggregate Municipality-level analysis, Zegras and Gakenheimer (2000) find no statistically significant relationship between the simple measures of population density and either public transport or walking trips (controlling for auto ownership). Both of these analyses draw from aggregated summary data from the 1991 household travel survey and offer few concrete conclusions. For example, Municipal-wide density is

---

<sup>159</sup> It is important to keep in mind that, in the analyses presented in the following sections, the built environment metrics are derived at the TAZ level.

<sup>160</sup> Note, the Kain and Liu (2002) analysis was originally conducted in 1996, but only recently published.

simply too gross of an indicator (the average size of a Municipality is roughly 16 square kilometers) to reflect local conditions which might really impact travel behavior.

More recently, as part of a project funded by the Global Environment Facility (GEF) looking to reduce greenhouse gas emissions from Santiago's urban transportation sector, the University of Chile's Transport and Land Use Laboratory (LABTUS) conducted a preliminary study to evaluate the impacts of transport and land use projects and policies associated with revitalization of the city center (Universidad de Chile, 2002). Utilizing an integrated transportation and land use modeling framework, the analysis assessed several different scenarios for land use and transport project development and their emissions implications and finds that only a program combining aggressive land use intensification with major transport system improvements would achieve any reductions in fuel use. The modeling analysis focuses on metropolitan-scale and meso-scale effects of changes in urban land use; it does not, however, look specifically at micro-level effects on travel behavior.

In an earlier analysis of the 1991 travel survey data, I followed the Boarnet & Crane (2001a,b) and Greenwald and Boarnet (2001) approach (see Chapter IV, Section IV.3.3.2) to assess the influence of three gross measures of urban form on travel behavior in Santiago, using household travel survey data from 1991 (Zegras, 2004). Specifically, controlling for socioeconomic, demographic factors and trip cost variables at the scale of the traffic analysis zone (TAZs), I looked at the influence of population density, relative share of commercial and service land uses, and relative share of vacant land on an individual's propensity to make home-based, non-work, non-school (HB NWNS) walking trips. Consistent with intuition, the model results suggested that an increased share of commercial and service uses in the zone of trip origin increases the likelihood of making HB NWNS walk trips, while vacant land intensity decreased the probability. Somewhat surprisingly, population density in the zone of origin had no significant effect. Overall the models had little explanatory power, suggesting possible mis-specification and/or poor measures of land use (which was likely, given the wide range in TAZ size: from 0.06 km<sup>2</sup> to 27.7 km<sup>2</sup>, with an average size of 1.3 km<sup>2</sup>). Furthermore, as mentioned in Chapter IV, Section IV.3.3.2, the Boarnet and Crane approach has several shortcomings.

Finally, and most recently, LABTUS carried out another analysis of the potential role for land use to influence travel behavior with the express purpose of reducing greenhouse gas (GHG) emissions (LABTUS, 2005). The study utilized the 2001 travel survey as well as the 2001 land use cadastre.<sup>161</sup> LABTUS developed an integrated suite of models to simulate transportation and land use market equilibriums and to identify optimum land use patterns (with the goal of minimizing GHG emissions).<sup>162</sup> Particular effort was made

---

<sup>161</sup> Apparently, this is the same raw data source utilized in my analysis; in fact, LABTUS formally organized and maintained the land use activity data (real estate cadastre) for SECTRA.

<sup>162</sup> The transport demand model consists of an integrated multi-stage set of discrete choice models of trip generation, trip distribution and mode choice; route choice was not included in the analysis, so congestion effects were not considered. A land market model calculates the subsidies that would be required to make households and firms locate according to the "optimized" (in terms of GHG emissions) city.

to effectively model walk trips, in the face of the important role of this mode in Santiago and, of course, its non-polluting nature. The model focused primarily on meso-level effects; according to the report, micro-level influences (land uses in the origin zone and the destination zone for trips under 5 kilometers) had minimal influence on the probability of walking.<sup>163</sup> Browne et al. (2005) suggest several useful extensions to the LABTUS work, including: extending the analysis to account for off-peak travel and weekend travel; assessing more thoroughly the degree to which *micro*-level urban design might influence travel behaviour; developing a vehicle ownership model that also reflects sensitivities to land use variations; among others.

## IX.2 Household Motor Vehicle Choice

Theory suggests that the choice to own an automobile would be influenced by where we live: both micro design factors and meso-level locational relativity. At the micro level, factors such as parking hassle, the relative utility of having a vehicle (i.e., convenience of alternative travel options) would influence auto ownership choice. What role, if any, do these influences have in rapidly motorizing Santiago?

### IX.2.1 Motor Vehicle Ownership Patterns and Evolution

Before looking specifically at motor vehicle ownership, it is interesting to examine the patterns of motor vehicle driver's licenses and their changes in time. One might think that in a developing country context (particularly in a county with national identification cards, and thus no need for drivers' license per se), few households without a motor vehicle would have a drivers license. As seen in the previous Chapter, the *average* city-wide ratio of motor vehicle licenses per household has basically reached one. This does not mean, however, that all household now have driver's licenses. In fact, nearly 40% of households in 2001 still had nobody with a driver's license (still a dramatic decline from 56% non-licensed households in 1991). In comparison, almost 60% of households in 2001 still had no motor vehicle (Table IX-1).

**Table IX-1. Number of Four-Wheel Motor Vehicles and Driver's Licenses per HH**

Number of Vehicles and Number of Driver's Licenses Per Household	4 Wheel Motor Vehicles		Driver's Licenses	
	1991	2001	1991	2001
0	65.8%	56.7%	56%	39%
1	26.7%	33.0%	28%	35%
2	5.9%	8.1%	12%	19%
3+	1.7%	2.2%	4%	7%

In other words, more households have drivers licenses than have cars today, and the rate of households' departing the "no driver's license" category was nearly three times the

<sup>163</sup> Examining trips under 5 kilometers and land uses in the origin and destination zones offered a way to roughly capture walk "corridor" effects; residential, service and office uses in the origins and destinations do exhibit statistically significant effects, but not always of the expected sign (LABTUS, personal communication, January, 2005) – the dependent variable was aggregate walk mode share generated in a given zone. Interestingly, these results are somewhat consistent with those of Zegras (2004) suggesting, indeed, the existence of local-level land use influences on, at least, walking behavior.

rate of households' leaving the no motor vehicle category. A growing number of households have potential vehicle use (at least someone with a drivers license), but still no car. This indicates, possibly, some aspiration to soon to get a car and/or expected access to someone else's vehicle.

### IX.2.2 A Note on Accessibility in the Motor Vehicle Choice Model

As mentioned, theoretically the relative convenience of alternative travel options may well influence the utility an individual or household derives from vehicle ownership. All else equal, a household that can more easily access other desired destinations without using an automobile will have less use for an automobile. Therefore, that household's probability of owning an automobile will be lower. As discussed in Chapter III (Section III.2.2), several different ways of measuring accessibility exist and, furthermore, these measures can be used both as variables (inputs) in analyses, outputs from analyses (i.e., indicators), or both. For the motor vehicle ownership model, I use accessibility as a model input; in this case, accessibility represents a theoretical measure of a household's potential access to all other relevant locations in the city. A traditional, Hanson-type gravity model formulation is used (see discussion in Chapter III):

$$A_i^m = \sum_{j \in L} w_j f_{ij} * 100 \quad (9.1),$$

where:

- $A_i^m$  is the accessibility measure for mode  $m$  in zone  $i$ ,
- $L$  is the set of all zones,
- $w_j$  is zone  $j$ 's share of all  $W$ ,
- $W$  is the total square meters (constructed floor area) of commercial and services, health, manufacturing, offices, social and community services, public administration, indoor sports facilities, and housing; and, the total square meters (land area) of parks and outdoor sports facilities,
- $f_{ij}$  is  $\exp(-b TT_{ij}^m)$ ,
- $TT_{ij}^m$  is the travel time for mode  $m$  from zone  $i$  to zone  $j$ , and
- $b$  is a parameter representing travel time sensitivity.

For this case, only travel times for automobile and bus were included. The travel times come from an ESTRAUS model (Santiago's travel forecasting model) run provided by SECTRA for the year 2001, AM peak period. For bus, the travel time included in-vehicle time, access and egress time and wait time.<sup>164</sup> In rigor, the  $b$  parameter should be

---

<sup>164</sup> The travel times were provided for fewer zones (410) than the 2001 origin destination survey (which included 780 zones, including external zones; my analysis used just 738 of those zones), as they came from a model run carried out before implementation of the updated zoning system. Unfortunately, and oddly enough, the 2001 OD zones did not always represent a disaggregation of the 410 ESTRAUS zones; in a few cases, an ESTRAUS zone was split into portions of different 2001 OD zones. I took the following steps to rectify the problem: the land uses in the 2001 zones were given to the ESTRAUS zones using utilities in ArcMap. The gravity calculation was then made for the 410 ESTRAUS zones. These zones were then spatially joined to the 2001 OD households, to give each HH an ESTRAUS zone ID and, in turn, the

empirically derived from a trip distribution model. In this case, a value of 0.4 was used (de Cea et al., 2004). Within zone opportunities were not included in the accessibility metric due to the unavailability of relevant travel times. However, as several land use measures from the household's home zone were included in the model, these serve as proxies for local level accessibility.

### **IX.2.3 Model Specification, Estimation, Results**

To determine what influence the built environment has on motor vehicle ownership, I estimated a multinomial logit model (see Chapter III, Section III.2.1.1) of motor vehicle choice by household. The alternatives available to a given household are zero, one, two, or three (or more) motor vehicles. An incremental model specification approach was taken. The basic model included only household socioeconomic and demographic characteristics, with transportation performance characteristics (zonal level accessibility; equation 9.1) then added, and, finally, meso- and micro-level built environment characteristics included. Only variables that were significant at greater than 95% and that increased the model goodness of fit (as measured by the likelihood ratio test) were retained in the final model specification.

Table IX-2 presents the model results. The parameter estimates, in all cases but one (discussed further below), carry the expected signs and are highly statistically significant and the model displays a high goodness of fit as measured by the rho-square value. The parameter estimates (the "Beta" column for each vehicle choice) are not directly comparable within each choice bundle, but they are comparable across bundles. In other words, one cannot directly compare the influence of, for example, household income with dwelling unit density in the household probability of owning two vehicles by simply looking at the relevant "Betas." One can, however, use the "Beta" values to compare the influence of the relevant variable across vehicle choice decisions (as clarified in the discussion below). To compare the influence of the different variables within each choice set decision, Table IX-3 presents a statistic analogous to the standardized coefficient value from a traditional ordinary least squares regression (following Levine, 1998). The statistic is calculated by multiplying the variable's "Beta" value times the standard deviation of the variable within the choice set. This "relative importance" statistic indicates the relative contribution of the variable to the choice process since this contribution comes from the size of the "Beta" value and the variation of the relevant variable.<sup>165</sup>

---

relevant accessibility measure. One ESTRAUS zone (270, in the Southeastern foothills) had an auto travel time of zero; it is unclear why. This zone was assigned an average value from the surrounding zones.

<sup>165</sup> For large "Beta" values, but little variation in the relevant variable, the variable will be relatively unimportant to the choice; high variation in the variable, with a small "Beta," will similarly mean little effect. The measure provides two advantages over the conventional multinomial logit elasticities: (1) it is constant over the range of the variable and (2) it includes information on the variation of the independent variable across the choice set (Levine, 1998).

**Table IX-2. Multinomial Logit Model of Household Motor Vehicle Choice<sup>166</sup>**

Variables	0 Vehicles (base)	1 Vehicle		2 Vehicle		3+ Vehicle	
		Beta	Robust T-test	Beta	Robust T-test	Beta	Robust T-test
<i>Household Characteristics</i>							
HH Income (US\$ 000s)		0.169	27.824	0.211	28.312	0.225	26.665
Adults per HH		-0.143	-5.775			0.699	9.700
Number Persons in HH		0.057	3.614	0.063	3.178	-0.277	-4.574
<i>Transport Characteristics</i>							
LN(Ratio of Auto to Bus Accessibility)		0.069	4.315	0.092	2.670	0.092	2.670
<i>Meso- and Micro BE Characteristics</i>							
Live in Apartment (Dummy)		-0.423	-7.553	-0.724	-6.547	-1.270	-5.524
Dwelling Unit Density (# dwelling units per hectare of constructed area)				-0.011	10.339	-0.019	-7.784
Diversity Index				-3.710	-7.859	-6.896	-7.327
Distance to CBD (KM)				0.030	3.213	0.030	3.213
Constants		-2.007	-23.975	-3.273	-14.699	-4.819	-11.956
Chosen Observations	8632	4662		1135		300	
% of Observations	59%	32%		8%		2%	

Notes: all variables included significant at > 95%; Sample Size: 14729; Null Log-Likelihood: -20418.7; Final Log-Likelihood: -11207.7; LR Test: 18422; Rho-Square: 0.451.

Starting with basic household socio-economic characteristics, we see the expected effect of household income; the effect is positive and increasingly influential with the decision to own multiple vehicles (comparing across the “choice bundle” of number of motor vehicles to own; Table IX-2). Looking at the relative importance of household income (Table IX-3), this variable dwarfs all others. This confirms our expectation that as soon as income allows, at least one vehicle in a household is almost a certainty. The variable adults per household presents slightly strange results. The variable only entered significantly into the decision to own one or three or more vehicles and in both cases is the next most influential variable. However, in the one vehicle ownership case, the effect is negative, meaning all else equal, the probability of a household owning 1 vehicle (relative to zero), declines with an increased number of adults in the household. I cannot come up with an intuitive explanation for this result. On the other hand, the number of

<sup>166</sup> When a cell in the table is blank, it means that variable was not included in the choice’s relative utility function. The choice of variables began with theory, with final variable inclusion based on normally-utilized measures of significance (i.e., T-test) and goodness of fit (the likelihood ratio test). When a parameter value is the same across choice sets (in the case of the ratio of auto to bus accessibility and distance to CBD for 2 and 3+ vehicle choices), a single parameter was estimated for the two choices (this proved to be the best model specification).

persons per household exhibits roughly comparable, positive influence on the decision to own one or two vehicles, but is negative in the case of three or more vehicles. This latter result may reflect the fact that, *all else equal*, as the household size increases the attractiveness of owning many vehicles declines due to household budgetary constraints (i.e., more money is required to clothe, feed, etc. the household members, reducing possible vehicle expenditures).

**Table IX-3. Relative Importance (D) of the Independent Variables to the Household Vehicle Choice Probabilities**

Variable	1 Vehicle			2 Vehicle			3 Vehicle		
	Beta	S.D.	D	Beta	S.D.	D	Beta	S.D.	D
<i>Household Characteristics</i>									
HH Inc. (US\$ 000s)	0.169	11.734	1.983	0.211	20.969	4.424	0.225	32.822	7.385
Adults per HH	-0.143	1.165	-0.167	n.s.		n.a.	0.699	1.495	1.045
Number Persons/HH	0.057	1.654	0.094	0.063	1.605	0.101	-0.277	1.998	-0.553
<i>Transport Characteristics</i>									
LN(Ratio of Auto to Bus Accessibility)	0.069	1.261	0.087	0.092	1.253	0.115	0.092	1.433	0.132
<i>Meso- and Micro BE Characteristics</i>									
Live in Apartment (Dummy)	-0.423	0.390	-0.165	-0.724	0.386	-0.279	-1.270	0.322	-0.408
Dwelling Unit Density	n.s.		n.a.	-0.011	55.407	-0.609	-0.019	48.357	-0.919
Diversity Index	n.s.		n.a.	-3.710	0.103	-0.382	-6.896	0.088	-0.610
Dist. to CBD (km)	n.s.		n.a.	0.030	4.081	0.122	0.030	3.785	0.114

Note: Beta comes from the household vehicle choice model (Table IX-2); S.D. is the standard deviation of the relevant variable within the choice set for the household. For the case of the dummy variable (for living in an apartment), the standard deviation does not really make substantive sense (since the possibility is to live in an apartment or not); the usefulness of the relative importance indicator (D) in this case is limited.

Turning to the relative transportation levels of service and built environment variables, we see a positive effect of the auto-to-bus accessibility ratio, an effect fairly comparable across the choice sets.<sup>167</sup> When a household lives in a zone with poor bus accessibility relative to auto accessibility, the household's probability of auto ownership increases. Finally, looking at the built environment characteristics, we see that, with the exception of the effect of apartment living, the built environment exhibits no influence on the probability of a household owning at least one vehicle. As the choice becomes to own more than one vehicle, however, we discern a built environment influence, specifically dwelling unit density, the diversity index (as derived in Chapter VII, Section VII.3.4) and

<sup>167</sup> The modal accessibility variables were tested independently also (i.e., auto accessibility, bus accessibility), however the ratio off the two variables (representing relative attractiveness of auto) proved to be the best model specification. Furthermore, the effect of this variable does not differ across the choice of 2 or 3+ vehicles (see footnote 166).

the rough meso-level variable of distance to CBD.<sup>168</sup> In zones with a high diversity index, the probability of owning two or three vehicles declines, with the effect increasing as the choice becomes owning more vehicles. The same can be said for dwelling unit density and apartment living. The influence of these variables on auto ownership may partly reflect reduced need for auto ownership (e.g., a high mix of local uses, represented by a high diversity index, means less need for automobiles). These variables may also represent some degree of auto ownership hassle and cost. In the case of apartment dwelling, for example, the issue of vehicle garaging plays a role. Dwelling unit density (in this case, measured as number of dwelling units per amount of total constructed space, in order to account for the fact that some zones may have a very large amount of undeveloped land, but with very dense developed areas) also reflects some amount of land scarcity for vehicle storage. Other built environment variables, including block morphology and intersection density (3- and 4-way) were tested, but showed no discernible influence.

#### **IX.2.4 Discussion**

Overall, the model offers an interesting glimpse at the factors influencing the household vehicle ownership decision. As we might expect, household income dominates the choice process. Nonetheless, some role of the built environment (as well as relative transport levels of service) can be detected, particularly when the household choice is to own two or three or more motor vehicles. It is interesting to compare the results with similar types of models estimated in the United States. For example, Hess and Ong (2002), using an ordered logit model of the household decision to own no automobiles in Portland Oregon, find a significant and positive effect of TAZ land use mix.<sup>169</sup> Cambridge Systematics (1997) reports significant effects of population density and a public transport-to-highway access ratio in an ordered logit model of household vehicle availability in Philadelphia.<sup>170</sup> Using a multinomial logit model, Cambridge Systematics (2002b) estimated a vehicle availability model for San Francisco, also finding significant effects of a public transport-to-auto accessibility ratio for two or and three or more vehicles, significant effects of dwelling unit density for all three vehicle choice options, and nearly significant effects for a “vitality index,” again for the two and three vehicle choice decision. Kitamura et al (2001), on the other hand, while finding some evidence of residential density influencing autos per household member, find no significant influence of regional accessibility measures (transit or auto; they do not, however implement a relative accessibility ratio), leading them to conclude that in a highly motorized region like Southern California accessibility may have marginal, if any, effects.

---

<sup>168</sup> One would expect some degree of correlation between these variables; indeed dwelling unit density and the diversity index are significantly and highly negatively correlated (-0.643), while the auto:bus ratio and distance to CBD are significantly and highly positively correlated (0.559); the model may, thus, suffer from some multi-collinearity problems.

<sup>169</sup> In this case, land use mix was a simple dummy variable, representing a zone with “good” land use mix (Hess and Ong, 2002).

<sup>170</sup> The public transport-to-highway access ratio is measured as employment reachable by certain time by public transport and highway. They also included a zonal “pedestrian environment factor” which was not quite significant.

That model estimated for Santiago produces results somewhat similar to several models for households in US cities is interesting in itself; despite motorization rates roughly 20% of US levels and much more rapid growth in the motor vehicle fleet, an effect of relative transportation levels of service and local land use characteristics can be detected. Any indications for policy related to land use planning and urban design influences need to be cautious and not overly optimistic, however. First, income still clearly dominates the ownership decision. Second, certain factors, such as the effect of apartment living, are not necessarily land planning policy variables, per se. This is particularly the case if we consider that this model does not account for potential self-selection: the fact that some households may choose their location (e.g., apartment and/or area with a high diversity of land uses) because of a preference for not wanting to own more than one automobile. At the same time, the model results do suggest that the built environment and relative accessibility should be incorporated into travel forecasting for Santiago; something which currently (to the best of my knowledge) does not happen in the city. Planning authorities currently utilize a household type approach (i.e., cross-classification) for forecasting auto ownership categories; no spatial variation in ownership is apparently accounted for. Such an approach could bias modeling results and policy analysis in ways even as simple as regulations regarding parking requirements for residential developments. The results presented here suggest more resolution in analysis could be valuable.

### **IX.3 Vehicle Use**

After household vehicle ownership is determined, how much automobile use will the vehicle-owning household undertake? After all, as proposed in Chapter 3, sustainable mobility depends on mobility throughput, with increased automobile use, *all else equal*, a sign of a less sustainable mobility system. Put simply, does the built environment have an influence on automobile use?

Before setting out to answer this question one source of estimation bias should be noted: auto driver trips generated by households with no vehicle as recorded by the survey. In 2001, the number of auto trips on a weekday reported by people with no car in the HH amounted to 4% of auto all driver trips; 27% of these are to work, 29% are "for work," with "errands" accounting for the next largest share, 21% (see Table IX-4). On the weekends (Saturday and Sunday combined), we see that auto driver trips by people from "auto-less" households account for 4% of all car driver trips; with still an important share of for work/to work (14%/25%), but also 19% shopping, 16% social, 18% other (which includes recreation).<sup>171</sup> This information seems to indicate some degree of vehicle sharing (i.e., informal car sharing), although whether this is among family, friends, or neighbors cannot be readily revealed by the data. To prevent possible bias in the vehicle use

---

<sup>171</sup> Relative to 1991, this is a decline in the total and relative number of auto driver trips by non auto-owning households. In 1991, apparently, 27% (!) of all car driver trips on a given workday were undertaken by individuals with no vehicle reported in the HH; 69% of those trips were to work another 8% were "for work." This likely represents work-provided vehicles increasing mobility. Note that the 2001 survey explicitly includes "Institutional" vehicles, while the 1991 survey did not; as such it is possible that the higher values in 1991 indicate vehicle use incurred by vehicles (work-provided) that were included in households' vehicle inventories for 2001.

estimation, only households with a motor vehicle recorded in the survey were included in the model estimating household total vehicle use.

**Table IX-4. Auto Driver Trips Made by Persons from Households with No Vehicle**

Purpose	1991		2001			
	Normal Weekday		Normal Weekday		Normal Weekend	
	Trips	Trip Share	Trips	Trip Share	Trips	Trip Share
To work	141,295	68.9%	51,764	27%	39,485	25%
To School	5,942	2.9%	3,966	2%	2,255	1%
Shopping	7,424	3.6%	13,897	7%	30,062	19%
Errands	18,691	9.1%	39,993	21%	12,782	8%
For Work	16,302	7.9%	55,505	29%	21,893	14%
Social	10,787	5.3%	9,018	5%	25,616	16%
Health	2,111	1.0%	195	0%	-	0%
Other	2,563	1.2%	14,532	8%	28,344	18%
Grand Total	205,115	100%	188,871	100%	160,439	100%

Sources: Derived from SECTRA, 1992b; SECTRA, 2002.

Notes: For 2001, Errands includes drop off/pick up someone/something; Social includes eat/drink and visit; Other includes recreation, religion, accompany someone and "other."

Overall, the annual intra-city vehicle use for a vehicle in Santiago averages approximately 8,000 kilometers per year (based on extrapolations using relevant expansion factors of household auto driver trips recorded in the 2001 survey) (see Table IX-5). This average value appears to be significantly lower than average annual vehicle usage rates recorded for Santiago from road-side odometer readings. Lepeley and Cifuentes (1997), for example, report that in 1996, one-year-old vehicles recorded an average annual kilometer reading of 23,000 kilometers. The large difference between the two values can partially be reconciled by the fact that the annual total estimated in Table IX-5 only accounts for intra-city travel (for example, 10 round trips per year to the nearest beach from Santiago would add an additional 3,000 kilometers to a vehicle's odometer) and, furthermore, represents an average across all vehicle ages (vehicle use declines with vehicle age; e.g., Lepeley and Cifuentes, 1997).

**Table IX-5. Estimated Intra-Urban Auto Use Per Vehicle in Santiago (2001)**

	Normal Season (kilometers)	Summer (kilometers)
Weekday	24/day	23/day
Saturday	22/day	19/day
Sunday	18/day	15/day
Weekly Total	63/week	58/week
Annual Total		8120/year

### IX.3.1 Model Specification and Estimation

To assess the influence of the built environment on household motor vehicle use, I estimated an ordinary least squares regression, predicting automobile use per auto-

owning household.<sup>172</sup> The dependent variable in this case was derived based on all auto-driver trips undertaken by the household on the day of the survey. The trip distance was derived from the geo-coded trip origin and destination and the shortest path on the road network. Trips with no derivable distance (due to lack of a geo-coded origin and/or destination) were assigned a dummy variable which was used as one of the dependent variables, with the expectation that the presence of such trips in the household would exert a downward influence on total auto distances traveled.<sup>173</sup>

Specifying and estimating such a model requires an important econometric correction to be theoretically consistent. Dubin and McFadden (1984) lay out the relevant theoretical framework, in the context of a household's choice for electric appliance ownership (a discrete choice) and electricity consumption (a continuous choice). The basic bias in such a model system comes from the fact that the ordinary least squares regression to estimate vehicle use is actually conditional on the vehicle choice (the discrete choice). This bias, known as selection bias, can be easily understood in the following way. The model used to estimate vehicle use can be estimated only for households who choose to own a car; those households may have specific (unobserved) reasons for using their vehicle intensively. Thus, we are estimating the vehicle use model on a sample that may be biased towards high usage households.<sup>174</sup> This "selectivity bias" can be corrected in the ordinary least squares regression of vehicle use by incorporating for each household a selection bias correction factor that is directly derived from the vehicle ownership model (estimated in the previous section). Dubin and McFadden show the approach to be consistent with utility maximization; Train (1986) offers a clear and comprehensive exposition and example application as does Mannering (1986). The selectivity bias correction factor takes the basic form of a ratio of the relevant multinomial logit choice probabilities<sup>175</sup> (Mannering, 1986), which enters as an independent variable in the vehicle usage (continuous choice, ordinary least squares) model.

Similar to the vehicle choice model, an incremental approach was employed, starting with household socio-economic and demographic characteristics, and then adding measures of the built environment. Ultimately, several built environment variables, representing meso- and micro-scale influences proved to be significant explanatory variables (see Table IX-6). Overall, the model has fairly good explanatory power (R-square of 0.27), particularly considering the disaggregate nature of the data and the fact that only a single day's automobile use is predicted. Similar vehicle use models,

---

<sup>172</sup> The approximately 1.6% of households in Santiago that made auto driver trips despite having no vehicle were excluded from this analysis.

<sup>173</sup> Whether the auto trip was "external" to the study area was also coded and included as an independent variable, but it had no significant explanatory power.

<sup>174</sup> Technically, the error term in the least squares regression may be correlated with variables that influence the vehicle choice probability, thereby violating a basic assumption of least squares regression (i.e., the expected value of the error term to be zero). More details can be found in Dubin and McFadden (1984), Train (1986), and Mannering (1986).

<sup>175</sup> Specifically:  $(1/K) \sum_{k \neq i}^K [P_k \ln P_k / (1 - P_k) + \ln P_i]$ , where K is the total number of alternatives and  $P_k$

is the predicted probability of choice k.

estimated on data for cities in the U.S. have displayed R-squared values in the range of 0.04 to 0.17 (e.g., Bento et al, 2004; Cervero and Kockelman, 1997; Kitamura et al, 2001).

Focusing on the standardized coefficients, we can see that the strongest explanatory variable is the total number of trips a household makes. This result suggests possible endogeneity bias; households with a propensity for mobility may travel further distances. The next most influential variable, is the number of vehicles within a household; this is controlling for possible selectivity bias in the sample, by applying the selectivity bias correction factor (which is significant), as discussed above (see, also, footnotes 174 and 175).

**Table IX-6. OLS Estimate of Household Total Automobile Use**

Category	Variable	Beta	Standard. Beta	Std. Error	T-Stat	Prob.
<i>Vehicles</i>	Share of “Green Autos” in HH	3270	0.057	1225.71	2.67	0.0077
	Number Vehicles	9130	0.253	1188.56	7.68	0.0000
	Avg. Vehicle Age	-255	-0.067	78.83	-3.24	0.0012
<i>HHs</i>	HH Income (thousands US\$)	69.6	0.052	26.68	2.61	0.0091
	# Drivers License	1029	0.037	539.17	1.91	0.0564
<i>Trips</i>	# Trips	925	0.281	60.16	15.38	0.0000
	No Distance coded	-1529	-0.089	266.68	-5.73	0.0000
	Normal Saturday	-2670	-0.032	1053.64	-2.53	0.0113
	Normal Sunday	-6749	-0.086	904.56	-7.46	0.0000
	Summer Sunday	-7346	-0.047	1753.67	-4.19	0.0000
<i>Urban Form</i>	Dist to CBD	0.59	0.109	0.125	4.74	0.0000
	Dist to Metro	0.61	0.074	0.196	3.11	0.0019
	Foothills	3100	0.035	1531.21	2.02	0.0430
<i>Urban Design</i>	4-Way Int. per KM	-1569	-0.048	490.60	-3.20	0.0014
	3-Way Int. per KM	479	0.035	210.20	2.28	0.0226
	Plaza Density	-16810	-0.022	7676.21	-2.19	0.0286
	Selectivity Bias Correction	5603	0.056	2081.5	2.69	0.0071
	Constant	-2108		2462.29	-0.86	0.39

Notes: the dependent variable is total auto distance traveled (in meters) by household on the day of the survey; R-square: 0.27; F-statistic 94.9 (Prob. 0.0); N=4,279; standard errors are heteroscedasticity-consistent (using the White correction).

Other vehicle-related variables reveal expected signs. The proportion of vehicles within the household that are not subjected to Santiago’s vehicle circulation restriction (*la*

*restricción*), represented by the variable “share of green autos” increases vehicle travel.<sup>176</sup> Second, the average age of the household’s vehicle fleet exerts a downward bias – the older the vehicles in the home, the less they are used.<sup>177</sup> Household income has a positive effect on vehicle use, as expected; while households tend to record lower auto distances on Saturdays and Sundays (including summer Sundays), relative to a normal work day.

Looking at meso-level land use measures, we see a fairly strong distance to CBD effect (comparable in importance to income), lending some support to the structural idea of the compact city. For each kilometer increase in distance from the CBD, we would expect a household’s daily auto use to increase by one-half a kilometer. We also see a not-insignificant influence of distance to the Metro. One way of looking at the influence of the Metro implied by this model is to use the model to predict a household’s auto use if all households lived at the mean distance to the nearest Metro station (for this sample, the mean household distance to the nearest Metro station is 4.2 kilometers). If all households that live within 1 kilometer (the average walking access distance for a Metro trip is 400 meters) of a Metro station instead lived at the mean distance, these households would, on average, travel an additional 3.8 kilometers per day by car.<sup>178</sup> Further extrapolating (albeit tenuously), if we consider that roughly 190,000 households (580,000 persons) live within 1 kilometer of the Metro and we assume that 40% of these households have an automobile, then applying this average auto travel reduction due to Metro proximity means that the Metro accounts for approximately 105 million fewer auto kilometers per year, or about 1.6% of Santiago’s annual auto use.<sup>179</sup> Finally, it is worth mentioning the apparent meso-level influence related to development in the Eastern foothills, which also is associated with an increase in automobile use.<sup>180</sup>

Few other micro-scale built environment factors associated with auto ownership had a significant influence on auto use in this model. The variables that do play an apparent role, albeit modest, are the number of 4-way intersections per kilometer (a proxy for grid street network intensity and thus neighborhood porosity), which was associated with reduced auto use, while the opposite was true for 3-way street intersections. All else equal, this suggests that the traditional street grid reduces auto use slightly. It is worth

---

<sup>176</sup> All vehicles with a catalytic converter are given a “green seal” and exempted from the vehicle restriction.

<sup>177</sup> Note that the household survey included data on each vehicle’s age and whether or not it had a “green seal” (see footnote 176); this information had to be averaged across the household’s vehicle fleet because information on the specific vehicle used by the household was not available.

<sup>178</sup> The approach was to estimate predicted HH auto use (in meters) at the **mean** household distance to Metro (4203 meters), using the coefficients from the model  $SHRAUTOSGR*3270+FOURW*9130-AVVEHAGE*255+HHINC*69+NUMDVLIC*1029+NVIJE*925-1529*ATNODIST-2671*NRMSADUM-6749*NRMSUDUM-7346*SUMSUDUM+0.59*CBDDIST+4203*0.61+3099*TOPODUM-1569*INT4PKM+479*INT3PKM-16809*PLZ\_DNSY+5603*SBC\_2$ . For the 541 auto-owning households that live within 1 kilometer of a Metro station, the average difference between the predicted auto use (at the mean distance) and the actual auto use equaled 3,776 meters.

<sup>179</sup> Assumes 365 days of effects; based on average intra-city vehicle use by *Santiagoños* of 8,400 kilometers per year and fleet size of 770,000 private vehicles.

<sup>180</sup> The assumption is that the hills make other travel modes less convenient. Nonetheless, the variable was only entered as a dummy for those zones in the foothills; as such, it may be capturing other unobserved effects associated with those parts of the city.

noting that a dummy for whether or not the household resides in a condominium was tested, with the goal of capturing potential “gated community effects” – under the supposition that such communities, typically with only one way in/out and a growing phenomenon in Santiago (see, e.g., Hidalgo, 2004) and elsewhere in Latin America, might increase auto use. No significant effect was detected.

## IX.4 Mode Choice, Destination Choice and Accessibility

The previous two sections have shown some detectable influences of meso-level urban form and micro-scale urban design characteristics on motor vehicle ownership and use. These influences may have important bearing on sustainable mobility since, as mentioned, motor vehicle use represents a throughput: a drain on capital stocks which, all else equal, we would prefer to reduce. But, is all else equal? Specifically, while the built environment apparently influences mobility levels, what does it do to *accessibility* levels? Can we find certain characteristics of the city that improve accessibility *and* reduce mobility? This Section presents a modeling framework and results that aim to answer this question.

### IX.4.1 Overview of Model Structure

As presented in Chapter 3 (Section III.2.1), I suggest the utility-based accessibility measure as derived from the random utility, discrete choice modeling tradition as a useful means of capturing the mobility benefit that an individual derives from the land use-transportation system. As presented schematically in Figure III-3 and represented in equations (3.2)-(3.8), the relevant choice process includes, at a minimum, the decision of where to go and what mode to use to get there. Since the probabilistic choice is based on the utility of the chosen option relative to the utility of the entire choice set, the utility of the entire choice set represents the expected maximum utility achieved from the relevant set of alternatives. For convenience to the reader, equation (3.8) is reproduced here:

$$E(\max_{i \in C_n} U_{in}) = \frac{1}{\mu} \ln \sum_{i \in C_n} e^{\mu V_{in}} \quad (10.2).$$

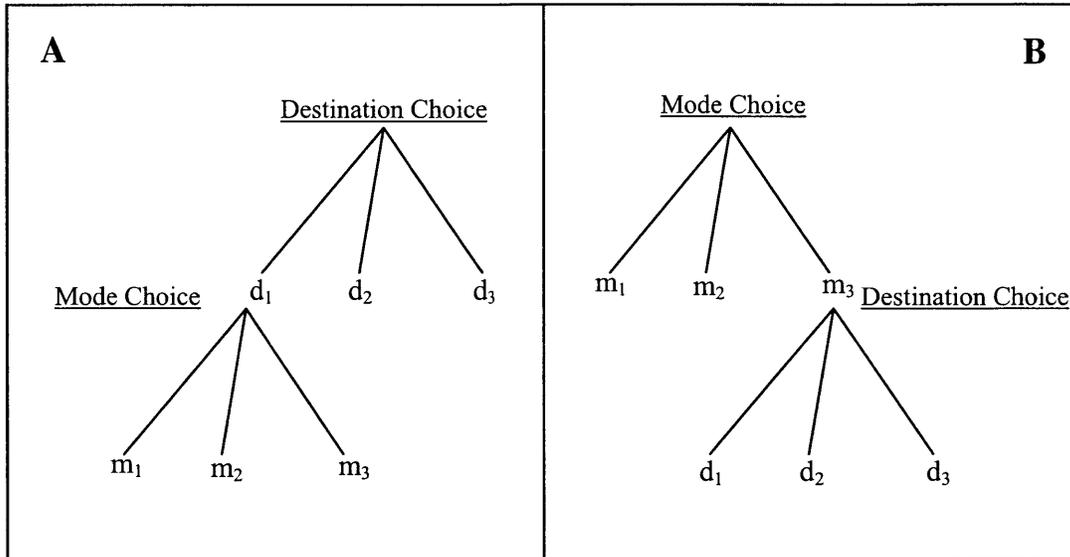
As discussed earlier, this measure, also known as the logsum or the “inclusive value,” links directly to consumer welfare theory. The logsum value provides the link between discrete choice models in the “nested” tradition, where the value of the decisions made at one nest level is then included in the value of the relevant options in the choice set at the upper nest level(s). Drawing from the simple travel mode and destination choice example, Figure IX-1 (expanded from Figure III-3) shows two possible structures for the relevant decision process. Note, as mentioned earlier, these structures do not represent a sequential decision process, but rather reflect the pattern of similarities within a choice process that occurs simultaneously. The nesting structure indicates the shared characteristics among the relevant alternatives in the choice process.<sup>181</sup> For example, in Figure IX-1A, the lower level mode choice is conditional upon the destination choice (at

---

<sup>181</sup> Again, refer to Chapter 3 for more detail on the requirements for the nesting structure. In short, it derives from the assumption regarding the form of the error term in the utility functions and the subsequent “independent from irrelevant alternatives” (IIA) restriction.

the upper, or root, level). In this case, the mode choices to get to destination 1 ( $d_1$ ) are positively correlated with each other, but are independent of the modes chosen to get to destination 2 or 3. In other words, the structure in Figure IX-1A implies that the decision-maker views the different modes available to get to destination  $d_1$  as more similar (i.e., they are positively correlated with each other) than all of the different possible destinations. In Figure IX-1B, on the other hand, the situation is reversed; the decision maker views all the places that one can go by a particular mode, such as auto, as more similar than the different potential places that one can travel to.

**Figure IX-1. Example Depiction of the Nesting Structure in a Simple Destination and Mode Choice Process**



In either case, the logsum value constructed from the systematic utilities of the lower level decision (e.g., the mode choice process in Figure IX-1A) provides a measure of the value for the relevant upper level decision (e.g., the modes available to get to a destination). That logsum value from the mode choice model, together with the other attributes of the destination that influence its attractiveness to the chooser, then influence the relative utility of the upper level choice. As presented in Chapter 3, logsum benefit values have been calculated in multi-stage multi-dimensional choice travel models (e.g., Hunt, 2002) and, more recently by Dong et al (2005) as an accessibility measure from a fully implemented daily activity schedule model. In the Santiago case, I hypothesize that the choice structure depicted in Figure IX-1A represents the individual's decision-making process for the relevant trip purposes analyzed. That hypothesis can be tested straightforwardly based on the value of the logsum parameter in the upper nest (as presented in Chapter III; Section III.2.1.1).

#### **IX.4.2 Trip Purpose Subset**

In estimating the accessibility metric for Santiago, I chose to focus on a subset of travel purposes, in particular non-work, non-school – or discretionary – trips. Several factors contributed to this choice. From an entirely practical perspective, focusing on discretionary travel, in which, in theory, there are few constraints on the destination

choice enables a simpler modeling approach. To effectively model trip purposes with destination choice constraints in at least the short- to medium-term (such as school and work trips) requires a significantly more complicated modeling approach, namely a doubly constrained integrated model well beyond the scope of this dissertation.

Beyond this non-trivial issue of practical convenience, the focus on discretionary trips offers several benefits. For example, from an urban planning perspective and with a specific interest in examining potential local-level built environment effects, the potential influence on discretionary travel cannot be ignored. That is, despite the long history of interest in the so-called jobs-housing balance, the reality remains that urban planning interventions can most likely more effectively influence travel for purposes other than for work simply because of the multiple constraints (skill sets, interests, etc.) on people's employment opportunities, constraints which extend well beyond any urban planners realm of influence (see relevant discussion in Chapter IV, Section IV.2). Some evidence suggests that local level influences on travel behavior are most relevant for non-work trips (e.g., Cervero and Radisch, 1996). In addition, discretionary travel has historically been under-analyzed, especially but not exclusively in developing countries. Looking at such travel, then, offers the promise of revealing new insights on trip types that are often ignored in analyses. Furthermore, while we can expect per person trip rates for school and work to remain roughly constant as income increases, we would expect an increase in discretionary travel. Finally, the data available from the Santiago 2001 household survey includes all days of the week, including weekends, during the entire year, which makes the data highly suitable for examining trips that do not occur during normal work days/seasons.

Within the discretionary travel subset, I further narrowed the trip purpose down into leisure trips, specifically recreation and social (visit) trips. Initially eating and drinking trips were also included in the subset, but I eventually excluded these trips due to modeling challenges discussed below. From a sustainable mobility perspective, the value of the leisure trip focus should not be discounted. On the one hand, leisure trips play an important role in individual benefit. On the other hand, leisure trips represent an important total share of mobility throughput in Santiago. For example, as presented in the previous Chapter (Table VIII-6) in terms of total annual passenger kilometers traveled (PKT), leisure trips account for 15%, the second largest single share, after work trips, of seven major trip purposes (including errands, health, shopping school and other). Leisure trips also account for the second highest share (20%) of total auto PKT and bicycle PKT (21%) after work trips, which poses the challenge of aiming to possibly mitigate future automobile use while also exploring the potential role of bicycling in this trip purpose. Finally, within leisure trips, automobile use accounts for 42% of PKT, followed by bus (38%), walk (9%), other (3%), taxi and bicycle (2%) each.<sup>182</sup>

---

<sup>182</sup> All of these values were derived from the origin destination survey, using all trips with derivable distances (3% of the 153,000 trips in the survey could not have the distance calculated). The expansion was based on the expansion factors provided for each relevant day of the week/season, and were expanded to the year accordingly. The figures reported in this paragraph likely *underestimate* the importance of leisure trips, since the single largest share of trip purposes with no distance derivable were leisure trips (1,681 trips; 33% of the total).

We should not overstate the value of the leisure trip focus. By their very nature, these are trips that typically occur off-peak and/or on weekends; as such, addressing such trips may not have important congestion-improvement effects. Nonetheless, in terms of mobility throughput, the value of focusing on leisure focus cannot be ignored.

### **IX.4.3 Lower Level Mode Choice**

#### *IX.4.3.1 A Note on Data Sources*

For the mode choice model, I originally intended to use the transportation levels of service provided by SECTRA, from the ESTRAUS model run for 2001 mentioned above (and utilized in the accessibility calculation in equation 9.1). Unfortunately, that approach proved untenable for a number of reasons. The primary problem arose from the difficulty in making the levels of service (which were provided for inter-zonal trips) comparable for intra-zonal trips. Since the focus of interest was full individual accessibility, being able to effectively model all trips, including very short walk and bicycle trips was critical. Developing separate levels of service variables for these trips and estimating a model using the combined levels of service did not seem advisable.<sup>183</sup> Further problems came from the different zoning structures between the OD survey and the ESTRAUS model run (which was based on a previous, more aggregate zone structure; footnote 164). Finally, the ESTRAUS model run was provided for the AM work day peak; a travel period which accounts for a small share of leisure trip-making.

For these reasons, instead of using the ESTRAUS runs, I estimated levels of service using the existing road network (for 1999), a map of bus lines, and the Metro network. For private autos, taxis, bicycle and walk, levels of service were estimated based on shortest road distance and estimated travel speeds (a congestion penalty was included for auto and taxi, based on time of day of travel, but with no spatial variation). For bus, levels of service were derived from shortest path on the bus line map (see Figure VIII-4) and, again, estimated travel speeds with a time-of-day congestion penalty. In this case, the greatest shortcoming came from not having the actual bus route information. In other words a trip from an origin to a destination followed any bus line, irrespective of whether or how many transfers might be required (as of 2001, Santiago's bus service was still fairly ubiquitous; nonetheless, this approach was admittedly crude). For access and egress times, the distance of the trip origin and destination to the nearest bus line was calculated. For shared fixed route taxis (*colectivos*), the service was assumed to follow bus lines, but with availability for a given trip specified based on whether a shared taxi trip was recorded in the travel survey originating and ending in the relevant zones. Access and egress times were calculated in the same way as for buses. Finally, for the Metro, the calculations were fairly straightforward, since just three lines operate; station distances and reported commercial speeds and headways were used and access/egress times were measured based on the nearest Metro station to the trip origin and destination. Due to lack of relevant information, intermodal transfer trips were excluded from the analysis.

---

<sup>183</sup> In any case, even roughly consistent levels of service across the two approaches (SECTRA-provided and local derived) could not be arrived at.

For travel costs, automobile costs were based on average vehicle fuel economy and gasoline prices as of 2001; the resulting value was US\$0.07 per kilometer. For taxi, known fixed (US\$0.25 for the flag down) and per distance fares (US\$0.67 per kilometer were used). For bus, the known fares were used (US\$0.48 cents for standard fare; US\$0.17 and no cost for relevant student fares were used, based on the travelers age). For Metro, peak and off-peak fares were used (US\$0.58 and \$0.48, respectively), based on the time of day of travel, and with student and senior fares (\$0.17) again used for relevant travelers based on age. For shared taxis, which employ tiered, distance-based rates, estimated values were used (derived from values reported in the OD survey). For the purpose of distributing auto and taxi trip costs among shared trips (i.e., with multiple travelers), the cost was divided by the number of travelers, when relevant.<sup>184</sup> For walk and bike trips, no out-of-pocket costs were included.

#### *IX.4.3.2 Model Specification and Estimation*

Based on the data described above a mode choice model was developed for all leisure trips and then separately for the trip sub-purposes: eating/drinking, visiting and recreation. The sub-purpose mode choice model performed considerably better, suggesting that the specific trip purpose has an important influence on mode choice. A satisfactory model for eating/drinking trips could not be estimated and those trips were eliminated from further analysis. The loss of information from these trips was not major, as they represented just 9% of the 15,000 total leisure trips in the sample. The results suggest that, possibly, eat/drink trips imply very different mode (-destination) choice decision factors relative to other trip types.

Many different model specifications were tried. These included a mixed logit model (which allows for random coefficient variation; i.e., taste heterogeneity in the population) as well as a model which included distance and income elasticity parameters, estimated simultaneously with the other parameters in the model (following Mackie et al, 2003). Ultimately, a straightforward specification was decided upon, in part due to the robustness of the results and the straightforward interpretation and use of the results in subsequent analyses (i.e., the destination choice stage).

Table IX-7 presents the mode choice model for visit trips. Several observations of interest can be made. One, we see a negative and highly significant effect of being a women on the probability of choosing the auto driver (AD) mode, suggesting that, all else equal, a woman in the household loses out to a man in the competition for the family car. Two land use variables figure significantly in the ultimate specification: the land use diversity effect in the zone of trip origin, which actually *reduces* the probability of walking<sup>185</sup> for

---

<sup>184</sup> This information was not directly provided in the survey; a query was developed to estimate shared trips originating from a household. Any trip by auto or taxi that departed from a household at the same time with the same purpose and the same destination as another trip from the same household was considered a "shared" trip, with costs allocated accordingly. There was no way to account for shared trips by people from different households, so some trip costs for these trips were overestimated. For auto passenger trips that did not have a matching household auto driver, the auto passenger was assumed to split the cost. and the cost was allocated among the number of travelers.

<sup>185</sup> This result runs somewhat counter to earlier analysis (Zegras, 2004), which found a positive influence of commercial and services land use on walk trip generation in the home TAZ (*not* the same as mode choice,

visit trips while increasing the likelihood of bus and Metro trips; and dwelling unit density, which increases the likelihood of walking for visit trips, an intuitive result.

**Table IX-7. Best Mode Choice Model Results for Visit Trips**

Modal Attributes	Value	Std Error	T-test	Robust Std Error	Robust T-test
Constant- AD	-1.380	0.374	-3.693	0.379	-3.640
Constant-AP	-3.331	0.366	-9.103	0.372	-8.967
Constant-BK	-2.142	0.377	-5.679	0.387	-5.528
Constant-BS	Reference				
Constant-M	-0.443	0.265	-1.673	0.290	-1.529
Constant-ST	-1.827	0.164	-11.128	0.171	-10.667
Constant-TX	-2.895	0.244	-11.852	0.258	-11.232
Constant-WK	0.449	0.368	1.221	0.388	1.158*
Cost/HH Income (cents/thousands US\$)	-0.012	0.002	-6.178	0.003	-4.665
Diversity Index-WK	-0.009	0.004	-2.505	0.004	-2.597
Diversity Index-M, BS	0.016	0.003	5.295	0.003	5.205
Dwelling Unit Density-WK	0.017	0.002	7.366	0.002	7.775
Female-AD	-1.034	0.116	-8.941	0.115	-9.018
HH Income (thousands US\$) -AD, AP	0.040	0.004	10.731	0.005	8.803
IVTT-BK	-0.081	0.007	-10.980	0.008	-10.481
IVTT-BS, M, AD, AP, TX, ST	-0.009	0.007	-1.317	0.007	-1.388*
IVTT-WK	-0.058	0.002	-29.056	0.004	-14.188
OVTT	-0.099	0.009	-11.073	0.009	-10.999
Vehicles per licensed driver-AD, AP	1.624	0.073	22.368	0.077	21.111
Wait Time (minutes)	-0.370	0.049	-7.543	0.050	-7.353

Notes: AD-auto driver; AP-auto passenger; BK-bike; BS-bus; M-Metro; ST-shared taxi; WK-walk; IVTT-in vehicle travel time (minutes); OVTT-out of vehicle travel time (minutes). N=7535; Null log-likelihood: -12809; Final log-likelihood: -6734; Rho-square: 0.47.\* signifies variable *not* significant at 95%.

It is important to note that a separate value of time coefficient was estimated for walk trips, bike trips, and motorized trips. The higher value for walk and the even higher value for bike show the relative disutility of these modes. In fact, using these coefficients, the coefficient on cost/income and the average annual household income (US\$10,000) and the estimated value of time of walking trips is US\$29 per hour and for biking \$40 per hour, compared to a reasonable US\$5 per hour for the motorized modes. While this result may partly be attributable to some of the data shortcomings mentioned above, neither should the result be dismissed out of hand. First, because the model produces an entirely reasonable value of travel time for motorized travel; second because values of time for non-motorized modes are not often calculated, so points of comparison are not readily

---

per se) using the 1991 survey data and much more crudely measured land use variables. It is not entirely clear if the difference is due to the modeling approach (mode choice, explicitly, as in this case; or implicitly, in the earlier case), the land use measures employed, possible behavioral changes over the two periods, or other differences.

available. A reasonable explanation for this result is that both of these non-motorized modes likely have a high distance sensitivity relative to the motorized modes.<sup>186</sup>

**Table IX-8. Best Mode Choice Model Results for Recreation Trips**

Modal Attributes	Value	Std Error	T-test	Robust Std Error	Robust T-test
Constant- AD	-0.481	0.379	-1.271*	0.373	-1.290*
Constant-AP	-2.066	0.366	-5.640	0.361	-5.728
Constant-BK	-0.921	0.376	-2.448	0.378	-2.439
Constant-BS	Reference				
Constant-M	0.948	0.239	3.974	0.255	3.715
Constant-ST	-2.542	0.170	-14.950	0.171	-14.856
Constant-TX	-3.150	0.252	-12.481	0.259	-12.168
Constant-WK	1.819	0.363	5.017	0.369	4.929
Cost/HH Income (cents/thousands US\$)	-0.010	0.003	-3.408	0.003	-3.711
Female-AD	-0.761	0.149	-5.113	0.148	-5.152
HH Income (thousands US\$)-AD, AP	0.035	0.003	10.324	0.004	8.407
IVTT-BK	-0.093	0.009	-10.574	0.011	-8.101
IVTT-BS, M, AD, AP, TX, ST	-0.021	0.010	-2.146	0.009	-2.233
IVTT-WK	-0.063	0.003	-25.075	0.005	-12.845
OVTT	-0.118	0.011	-10.566	0.014	-8.423
Summer dummy-BK	0.665	0.160	4.164	0.162	4.119
Topography dummy-BK	0.660	0.244	2.701	0.246	2.682
Vehicles per licensed driver-AD, AP	1.119	0.090	12.395	0.089	12.553
Wait Time	-0.145	0.049	-2.972	0.048	-3.021

Notes: AD-auto driver; AP-auto passenger; BK-bike; BS-bus; M-Metro; ST-shared taxi; WK-walk; IVTT-in vehicle travel time; OVTT-out of vehicle travel time. N=5404; Null log-likelihood: -9140; Final log-likelihood: -4568.8; Rho-square: 0.50.\* signifies variable *not* significant at 95%.

Table IX-8 presents the results for recreational trips. In this case, no local-level (i.e., home TAZ) built environment effects were detected. Summer time increases the likelihood of bicycle travel, while, oddly, so does residing in the zones in the foothills. This might be explained by the relative bicycling amenity associated to those areas (despite the topography; or, even, due to the topography) or the fact that the topography dummy may actually be capturing another unobserved characteristic of the relevant zones. Otherwise, similar results as for visit trips can be seen. If we trust the model specification and data, recreational trips have a higher in-vehicle time sensitivity and higher value of time, double that of visit trips for motorized modes and less than double that for the non-motorized modes.

<sup>186</sup> Such an effect might be modeled by including a travel cost associated with walk and bike travel that aims to account for the energy use (e.g., calories), which might have some form of step-wise and/or exponential function, indicating increasing cost penalty with distance (for example, some people might view a certain amount of caloric use as a benefit).

#### **IX.4.4 Upper Level Destination Choice**

As discussed in Section IX.4.1, the nested structure in Figure IX-1A represents the hypothesized decision structure for leisure travel in Santiago. In this structure, the estimates from the model of mode choice (conditional on the destination choice) presented in the previous Section, feed directly into the destination choice model, representing a composite index of relative travel benefit to the individual from the various available modes (to that individual for the trip).

##### *IX.4.4.1 A Note on Data Sources*

Travel times to all zones were calculated using TransCAD, zone-centroid to zone-centroid, to calculate a levels-of-service matrix for all 738 zones.<sup>187</sup> For public transport modes, access and egress times were calculated based on the zone centroid's distance to nearest bus line and Metro station. The same assumptions used above in the mode choice model were used.

##### *IX.4.4.2 Model Specification and Estimation Results*

A random set of 13 alternative destination zones was generated based on simple random sampling without replacement. To this alternative set, the actual destination choice was added. McFadden (1978) demonstrated that such an approach to destination choice modeling provides for consistent estimates.

While most of the variables display expected (or at least justifiable) signs, the parameter values on the Logsums derived from the lower level mode choice models exceed one<sup>188</sup> (indeed are significantly greater than one) for both visit trips and recreational trips (see Table IX-9 and Table IX-10). As discussed in Chapter III (Section III.2.1.1), for theoretical consistency in a nested logit model with the lower-level nest normalized to one, the value of the parameter estimated on the lower-level logsum in the upper level nest must be between zero and one. The model violates the underlying theory of the nested structure. What these results tell us is, that in the case of these leisure trips, the decision structure implied in Figure IX-1A – that the decision-maker views the different modes available to get to a leisure trip destination as more similar than all of the different possible destinations – does not hold. The next section, tests the alternative decision structure (Figure IX-1B).

---

<sup>187</sup> Sincere gratitude to Mikel Murga for his contribution to these estimates.

<sup>188</sup> As noted in Chapter 3, the sequential estimation procedure employed here produces consistent, but not efficient estimates. Generally, the estimated standard errors will be biased downwards. This bias shrinks with increasing sample size. In this case, due to the fairly large sample sizes and the fairly high T-statistics, it is probably safe to assume that the downward bias of the standard errors will not affect the significance of the relevant T-statistics

**Table IX-9. Destination Choice for Visit Trips:  
Destination as the Upper Level Nest**

Attributes of Destination Zone	Value	Std Error	T-test	Robust Std Error	Robust T-test
Commercial/Services	0.0003	0.0000	8.0815	0.0000	8.0619
Diversity Index	-0.0091	0.0035	-2.6103	0.0038	-2.4093
LOGSUM	3.0443	0.0456	66.7578	0.0511	59.6112
Manufacturing	-0.0002	0.0001	-2.6164	0.0001	-2.3434
Social and Community Services	0.0003	0.0001	2.5028	0.0001	2.2105
Plazas	-0.0004	0.0001	-3.5438	0.0001	-3.3943
Residential Dwelling Unit Density	0.0074	0.0020	3.6959	0.0021	3.5585
Same Sector Dummy	-0.3754	0.0613	-6.1263	0.0677	-5.5467
Ln(Zone Size)	0.8472	0.0431	19.6734	0.0447	18.9553
Sports Area	-0.0001	0.0000	-2.7151	0.0000	-2.4719
City Sector Dummy-North	0.7271	0.1317	5.5217	0.1446	5.0268
City Sector Dummy-West	0.5553	0.1297	4.2827	0.1430	3.8840
City Sector Dummy-East	0.3316	0.1310	2.5314	0.1417	2.3398
City Sector Dummy-South	0.4148	0.1296	3.2001	0.1426	2.9093
City Sector Dummy-Southeast	0.5806	0.1354	4.2878	0.1499	3.8732

Notes: N=7189; Null log-likelihood: -18972; Final log-likelihood: -4427.3; Rho-square: 0.77. For the Sector dummies, the reference case is the center of the city. All of the land uses are measured as densities (i.e., total built space or land area over the total size of the zone).

**Table IX-10. Destination Choice for Recreation Trips:  
Destination as the Upper Level Nest**

Attributes of Destination Zone	Value	Std Error	T-test	Robust Std Error	Robust T-test
Commercial/Services	0.0005	0.000	12.070	0.000	9.378
Diversity Index	0.0234	0.003	8.738	0.003	8.364
LOGSUM	2.3671	0.052	45.720	0.056	42.434
Manufacturing	-0.0003	0.000	-4.025	0.000	-3.982
Other Greenspace	-0.0003	0.000	-2.727	0.000	-2.696
Public Administration	0.0003	0.000	5.184	0.000	5.029
Parks	0.0001	0.000	6.591	0.000	6.710
Residential Floor Area	0.0001	0.000	3.824	0.000	3.775
Same Sector Dummy	0.8478	0.071	12.008	0.068	12.467
Ln(Zone Size)	0.4264	0.048	8.862	0.047	9.080
Sports Area	0.0002	0.000	7.115	0.000	6.664
City Sector Dummy-East	0.4045	0.087	4.635	0.084	4.842
City Sector Dummy-South	-0.4679	0.093	-5.015	0.087	-5.363

N=5306; Null log-likelihood: -11034; Final log-likelihood: -2873.3; Rho-square: 0.74. All of the land uses are measured as densities (i.e., total space over the total size of the zone).

#### IX.4.5 Alternative Model Structure

This Section presents the alternative model structure (Figure IX-1B), in which the traveler views all of the places that s/he can go by a particular mode, such as auto or bike,

as more similar than the different potential leisure trip destinations. The modeling process is, basically, the converse of the approach taken in the previous section.

*IX.4.5.1 Lower Level Destination Choice Models*

With destination at the lower level nest, the decision process reflects a destination choice conditional on mode choice. So, for each relevant trip observation in the survey, the destination choice model includes the relevant zonal characteristics (the same 13 randomly generated alternative destination zones were used) and the levels of service (in vehicle travel time, out of vehicle travel time and travel costs) implied for the observation’s chosen mode. In this case, different coefficient estimates for travel times for different modes cannot be estimated, losing the ability to differentiate between, e.g., the value of time for non-motorized versus motorized travel. In the case of both trip purposes, the model performed fairly well, but only after shared taxi trips were eliminated from the analysis and after wait times were combined with out of vehicle travel times.

**Table IX-11. Visit Trips Destination Choice Model Results: Destination as Lower Level Nest**

Attributes of Destination Zone	Value	Std Error	T-test	Robust Std Error	Robust T-test
Cost/HH Income (cents/thousands US\$)	-0.033	0.005	-6.263	0.012	-2.853
Commercial/Services	0.000	0.000	9.129	0.000	9.770
Diversity Index	-0.012	0.002	-5.614	0.002	-5.962
In-Vehicle Travel Time (minutes)	-0.093	0.002	-57.582	0.004	-26.036
Social and Community Services	0.001	0.000	7.100	0.000	7.065
Out of Vehicle Travel Time (minutes)	-0.086	0.008	-10.678	0.009	-9.117
Plazas	-0.000	0.000	-1.747	0.000	-2.206
Residential Dwelling Unit Density	0.015	0.001	11.192	0.001	11.871
Ln(Size)	0.638	0.029	22.429	0.028	23.223
City Sector Dummy-North	0.486	0.094	5.174	0.093	5.250
City Sector Dummy-West	0.507	0.093	5.434	0.092	5.490
City Sector Dummy-East	0.511	0.089	5.748	0.087	5.893
City Sector Dummy-South	0.327	0.093	3.509	0.094	3.492
City Sector Dummy-Southeast	0.511	0.098	5.228	0.099	5.150

N=7379; Null log-likelihood: -19473.6; Final log-likelihood: -9641.4; Rho-square: 0.51. Out of vehicle travel time includes wait time. All of the land uses are measured as densities ((i.e., total space over the total size of the zone).

The signs or significance of the relevant zonal attributes do not change for visit trip destination choice; commercial and services attract visit trips, as do social and community services and residential dwelling units. All else equal, all other parts of the city are preferred for visit trips relative to the city center. In this case, once again we can

derive an estimated value of time from the model parameters. At an average household income of US\$10,000 per year, the implied value is almost \$17 per hour. This is certainly a higher than expected value; however, given that the in-vehicle travel time in this case includes motorized and non-motorized travel, the higher relative value of time for non-motorized modes (seen in the previous mode choice model; see Table IX-7) seems to be “inflating” the overall value.

**Table IX-12. Recreation Trips Destination Choice Model Results:  
Destination as Lower Level Nest**

Attributes of Destination Zone	Value	Std Error	T-test	Robust Std Error	Robust T-test
Cost/HH Income (cents/thousands US\$)	-0.015	0.002	-6.183	0.003	-4.817
Commercial/Services	0.000	0.000	10.584	0.000	9.918
Diversity Index	0.024	0.002	10.373	0.002	10.130
In-Vehicle Travel Time (minutes)	-0.109	0.002	-46.128	0.005	-20.571
Manufacturing	-0.000	0.000	-5.386	0.000	-5.322
Out of Vehicle Travel Time (minutes)	-0.157	0.016	-9.905	0.029	-5.442
Public Administration	0.000	0.000	3.702	0.000	3.627
Parks	0.000	0.000	6.147	0.000	6.315
Residential Dwelling Unit Density	0.006	0.002	3.367	0.002	3.417
Ln(Size)	0.453	0.042	10.689	0.042	10.701
Sports	0.000	0.000	6.972	0.000	6.743
City Sector Dummy-East	0.476	0.070	6.805	0.067	7.105
City Sector Dummy-South	-0.514	0.081	-6.302	0.076	-6.726

N=5279; Null log-likelihood: -13931.6; Final log-likelihood: -4453.64; Rho-square: 0.68. Out of vehicle travel time includes wait time. All of the land uses are measured as densities (i.e., total space over the total size of the zone).

For recreation trips, the coefficients on and significance of relevant zonal land use attributes also do not change relative to the upper level destination nest estimation. Zones with high concentrations of commercial and services, public administration, parks, sports, and residential dwelling units attract recreation trips. Manufacturing activities deter recreation trip attraction. The Eastern part of the city, with a high concentration of natural amenities due to the foothills, attracts recreation trips relative to the rest of the city, while the generally lower income Southern part of the city also deters recreation trip attraction. Looking again at the coefficient estimates for in-vehicle travel time and cost/income, we can derive an estimated value of travel time at the average income of US\$10,000 per year. In this case, the relevant value is US\$42 per hour; this value clearly exceeds our expectations, although it is consistent with the higher value for recreation trips derived from the mode choice modeling above. Again, part of this high value results from the “inflation effects” of combining motorized and non-motorized travel times. But, this high value does suggest further model refinements may well be in order.

#### IX.4.5.2 Upper Level Mode Choice Models

As represented in Figure IX-1, the lower level destination choice model feeds into the relative attractiveness of the various modes, via the logsum. In this case, the logsum comes from the parameter estimates derived in the previous Section.

**Table IX-13. Best Mode Choice Model Results for Visit Trips:  
Mode Choice as Upper Level Nest**

Modal Attributes	Value	Std Error	T-test	Robust Std Error	Robust T-test
Constant-AD	1.716	0.127	13.474	0.127	13.558
Constant-AP	0.271	0.102	-2.647	0.105	-2.574
Constant-BK	0.797	0.124	6.442	0.129	6.192
Constant-BS	Reference				
Constant-M	0.073	0.131	0.554	0.151	0.483*
Constant-TX	-0.781	0.131	-5.986	0.137	-5.705
Constant-WK	3.275	0.103	31.784	0.116	28.118
Diversity Index-PT	0.018	0.003	5.938	0.003	5.712
Diversity Index-WK	-0.011	0.004	-2.919	0.004	-3.047
Dwelling Unit Density-PT	0.018	0.002	7.686	0.002	7.899
Female-AD	-1.071	0.115	-9.301	0.113	-9.445
Female-BK	-1.466	0.164	-8.961	0.165	-8.908
HH Income ('000s US)-AD,AP	0.041	0.004	11.077	0.004	9.144
LOGSUM	0.691	0.019	36.982	0.042	16.477
Vehicles per Driver-AD,AP	1.589	0.072	22.192	0.076	21.020

Notes: AD-auto driver; AP-auto passenger; BK-bike; BS-bus; M-Metro; WK-walk; N=7410; Null log-likelihood: -11954; Final log-likelihood: -6294.3; Rho-square: 0.47.\* signifies *not* significant at 95%.

Table IX-13 presents the mode choice model results for visit trips. Consistent with the previous mode choice model estimates, a local “home zone” built environment effect on mode choice is detected for the diversity index on walking trips and public transport trips and for dwelling unit density on public transport trips. Notably, being a female decreases the likelihood of choosing auto drive or bike (note that this controls for whether the woman has relevant access in the household to these modes<sup>189</sup>). Both household income and the number of vehicles per licensed driver in the house increase the likelihood of auto use (as driver or passenger). Importantly, the coefficient estimate on the Logsum value is positive and less than one (significantly less than one<sup>190</sup>); that is, this model structure satisfies the theoretical requirement of the nesting structure.

Table IX-14 presents the recreation trips mode choice results. Again, consistent with the previous estimates, no local-level built environment influences on mode choices were detected. Similar to the visit trips mode choice case, being a female reduces the likelihood of choosing bike or auto driver. The summer-time increases the probability of

<sup>189</sup> In the case of auto driver, availability depends on whether the person has a license and whether the household owns a vehicle; in the case of bicycle, availability more simply depends on whether a bicycle is in the house.

<sup>190</sup> Again, the standard errors are under-estimated; see footnote 188.

choosing the bike for recreational trip purposes. Income and vehicles per driver have similar effects as the visit trips case. Finally, and importantly, the coefficient estimate on the Logsum value is positive and less than one (significantly less than one<sup>191</sup>) in this case as well; in other words, this model structure for recreational trips also satisfies the theoretical requirement of the nesting structure. Based on these results, we can proceed to use the final model parameters to calculate logsum accessibility values.

**Table IX-14. Best Mode Choice Model Results for Recreation Trips:  
Mode Choice as Upper Level Nest**

Modal Attributes	Value	Std Error	T-test	Robust Std Error	Robust T-test
Constant-AD	0.869	0.121	7.193	0.121	7.182
Constant-AP	-0.720	0.076	-9.461	0.081	-8.939
Constant -BK	0.054	0.108	0.502	0.112	0.482*
Constant -BS	Reference				
Constant -M	1.289	0.137	9.424	0.152	8.467
Constant -TX	-1.856	0.132	-14.077	0.139	-13.380
Constant -WK	2.984	0.068	43.722	0.100	29.704
Female-AD	-0.815	0.148	-5.491	0.146	-5.572
Female-BK	-0.560	0.152	-3.684	0.156	-3.590
HH Income ('000s US)-AD,AP	0.037	0.003	10.780	0.004	8.857
LOGSUM	0.646	0.020	32.536	0.044	14.565
Summer-BK	0.674	0.161	4.197	0.166	4.065
Vehicles per Driver-AD,AP	1.087	0.090	12.128	0.088	12.324

Notes: AD-auto driver; AP-auto passenger; BK-bike; BS-bus; M-Metro; WK-walk; N=5339; Null log-likelihood: -8508.2; Final log-likelihood: -4291.9; Rho-square: 0.50. \* signifies *not* significant at 95%.

## IX.5 Accessibility, Sustainable Mobility, and the Built Environment

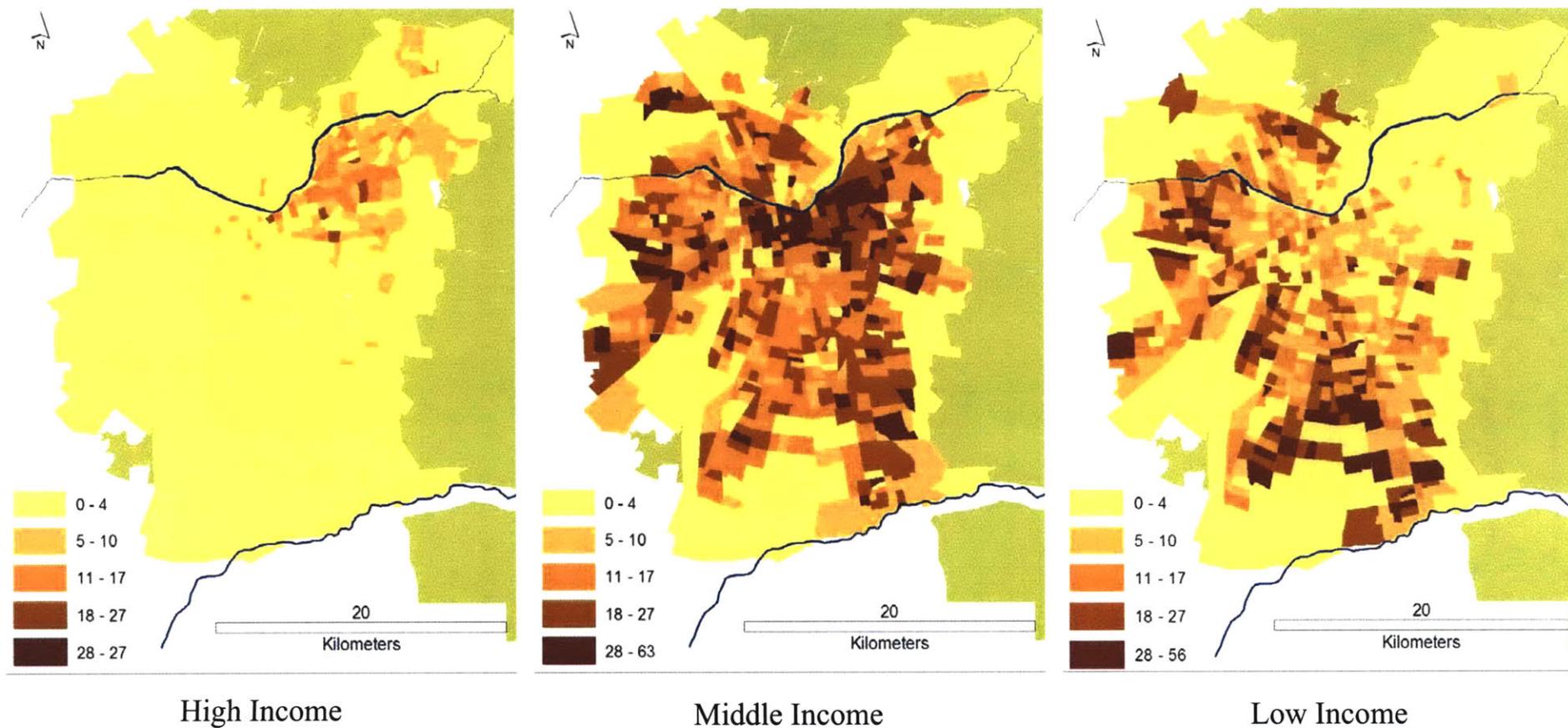
As discussed in Chapter 3, in order to make the Logsum accessibility measure comparable across individuals, both the scale and level conditions must be satisfied. Alternatively, spatial variation in the Logsum-based accessibility measure can be analyzed by comparing how the accessibility for a “representative individual” would vary if that individual were placed in different areas (TAZs) in the city. The latter approach is employed in this Section, in part due to the fairly straightforward interpretation of the results. To display the results, three different income categories are used, with the mean characteristics from the relevant sample used to represent income and auto ownership levels for representative male and female adults (each assumed, in the base case, to have the auto driver mode available; see Table IX-15). Figure IX-2 shows the relative distribution of the three income categories across the study area.

**Table IX-15. Basic Characteristics Used to Represent Adult Accessibility**

Variables	High Income	Middle Income	Low Income
Vehicles per Driver	.83	.4	.16
Average HH Income	US\$46,000	US\$10,000	US\$3,600

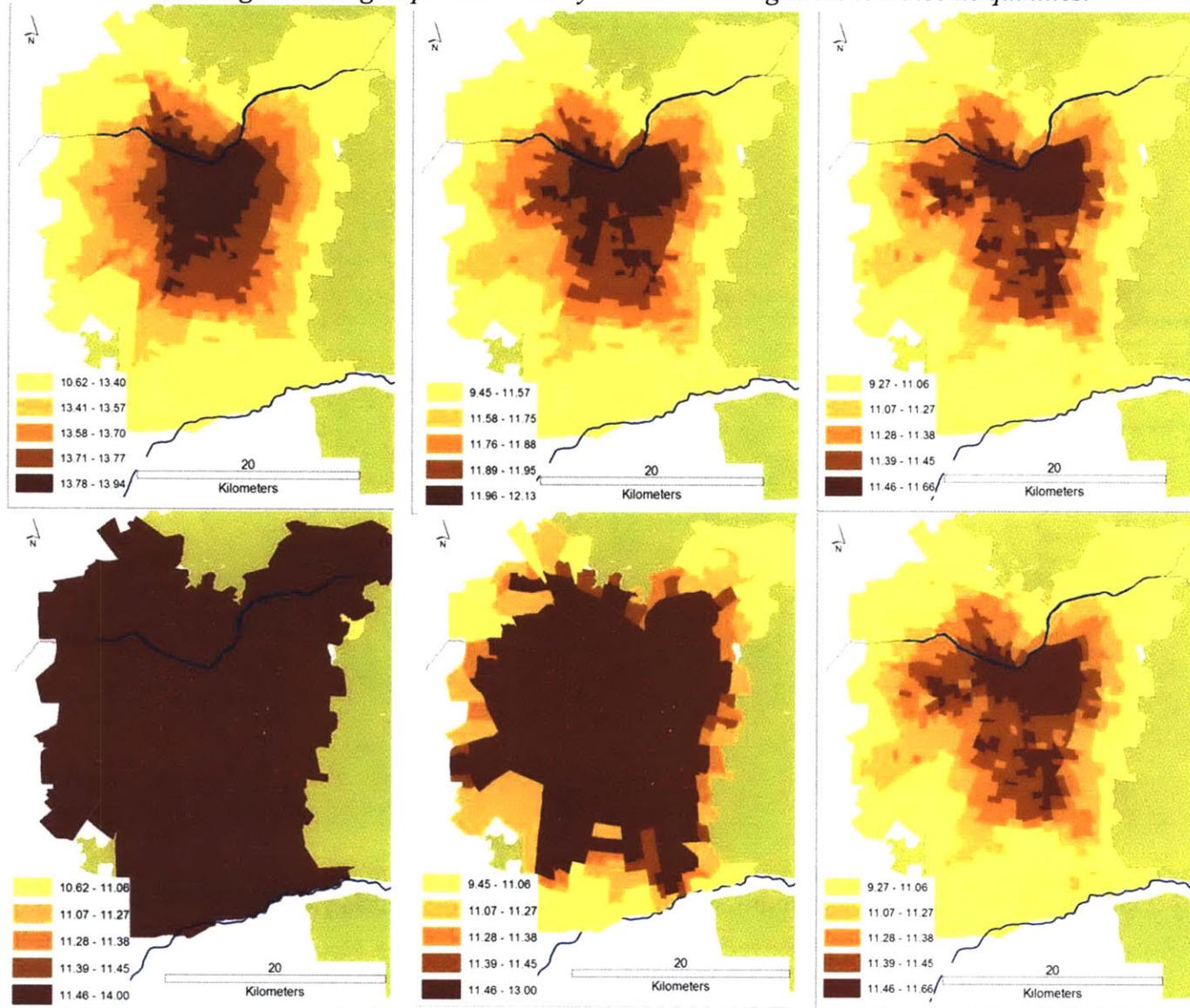
<sup>191</sup> See previous footnote.

**Figure IX-2. Density of Households (Households per Hectare) by Basic Household Income Category**

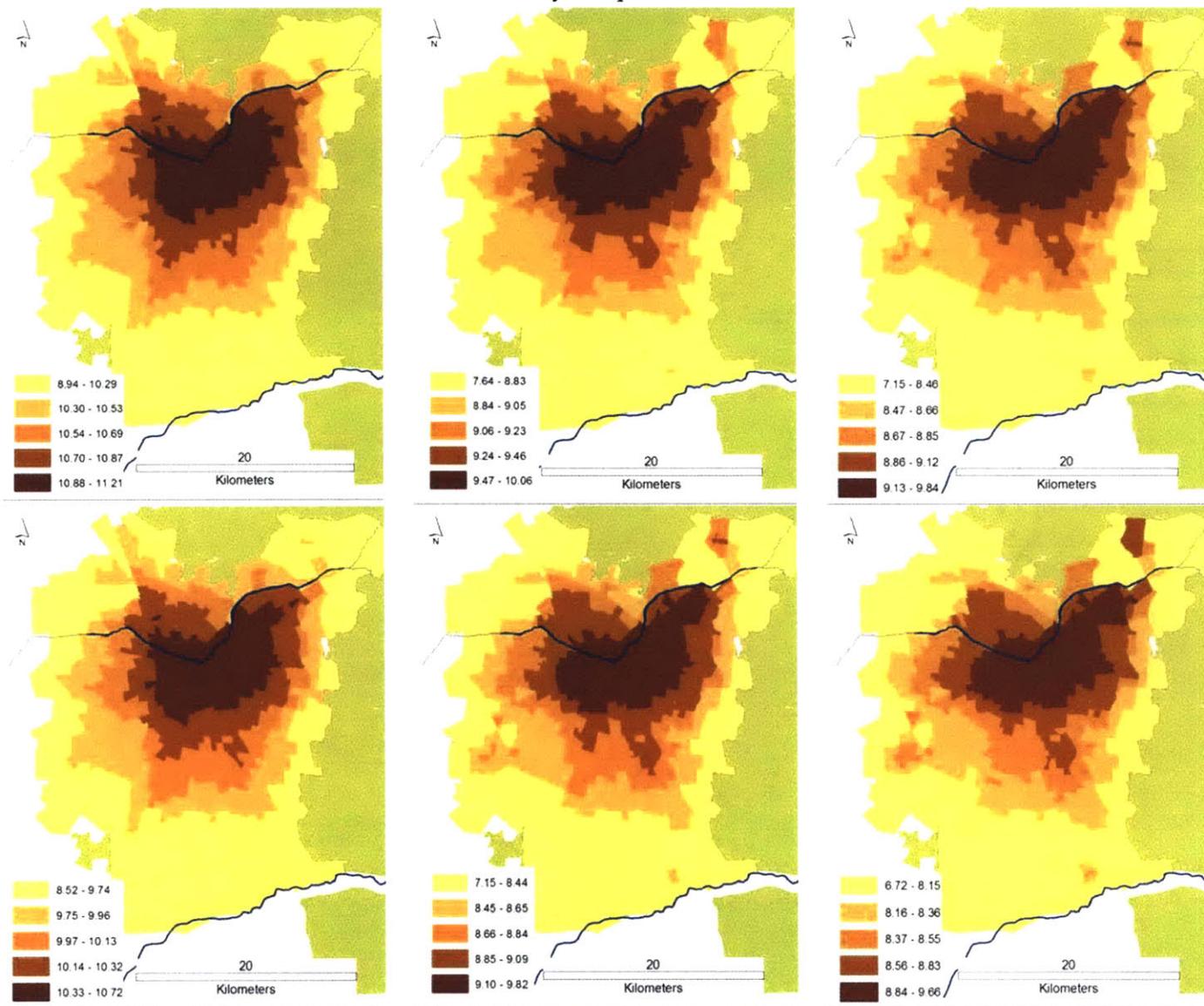


**Figure IX-3. Social Accessibility Levels (Logsum): Female Adult (High, Medium, Low Incomes; left to right)**

*The top three maps present zonal accessibility levels by quintile within the relevant income category; the lower three maps show the middle and high income groups' accessibility levels according to the low income quintiles.*



**Figure IX-4 . Recreational Accessibility (Logsum): Male (top) & Female (bottom) (High, Medium, Low Incomes; from left)**  
*In each map, the shades represent quintiles of accessibility within each income category; the values for men and women are not directly comparable.*



### IX.5.1 Basic Accessibility Levels for Visit and Recreation Trips

Figure IX-3 shows absolute social (visit trips) accessibility levels for an average adult female in the three different income categories. The most noteworthy characteristic, perhaps, is the heavy mono-centric orientation of accessibility levels.<sup>192</sup> Some degree of spatial variation in the most accessible zones for different income groups can be detected; this is primarily a reflection of the relative travel cost sensitivity of the different income groups. The top three maps in Figure IX-3 show the relative distribution, by quintiles, within each income category. Overall, it is clear that increased income translates into higher accessibility levels; the bottom three maps in Figure IX-3 show the distribution of middle and high income accessibility levels within the same quintiles as the low income. These figures show, basically, that a middle income woman would enjoy the same or higher levels of accessibility in roughly 70% of the city as a lower income woman would enjoy in just 20% of the city. In the case of the upper income woman, the figure shows that, basically, she would enjoy – anywhere in the city – higher levels of accessibility than a lower income woman would enjoy even if the lower income woman were to locate in her place of highest accessibility. Similar patterns emerge in the case of recreational accessibility, with gender playing little relative role (see Figure IX-4). Clearly, severe inequities in accessibility, the theoretical land use-transportation benefit, exist. The inequities can also be seen by comparing the areas of highest accessibility (recreational and social) for low income groups with the primary areas of concentration of low income households (Figure IX-2). In general, few low income households live in areas with high recreational and social accessibility.

#### IX.5.1.1 The Effects of Mode Availability on Basic Accessibility Levels

The logsum-based accessibility measure allows for examination of effects based on, for example, variation in modal accessibility. As an illustration, Figure IX-5 plots the share decline in recreation trip accessibility ( $[\text{Acc}_{\text{before}} - \text{Acc}_{\text{after}}]/\text{Acc}_{\text{before}}$ ) for a middle and low income female after losing auto, bike, or Metro availability. In the case of the loss of the auto drive option, the spatial patterns of effects are quite similar across the two income categories, although the relative accessibility declines are lower for the low income female (ranging from 1.1% to 6.6% for the low income case compared to 1.9% to 9% for the middle income case). Essentially, this result reflects the relative modal preference for automobile as income grows and the declining cost-sensitivity to auto with income increases; loss of this mode implies a sharper relative decline in utility-based accessibility for higher income groups. As we might expect, given relative cost sensitivity to other modes, the lower income female is worse off with the loss of the bike option, when compared to her middle income counterpart. Note, however, that the range of relative decline, even for the low income woman, is much lower (in the range of 0.3% to 1% for a low income female and 0.2% to 0.7% for the middle income) than that incurred from loss of the automobile option. Spatially, considerable differences exist in the effects of bicycle

---

<sup>192</sup> Note, as specified here, the model does not explicitly account for the specific qualities of the potential destinations. In this case, for example, the relative influence of socio-economic similarities (such as high income people possibly only wanting to visit high income people) possibly influencing potential zonal attractiveness was not included in the destination choice. The model specification could be improved in this regard.

loss on middle versus lower income cases. Finally, looking at the case of the Metro, we can see that the loss of this mode has a higher maximum share decline in accessibility relative to bike (e.g., 2% to 1%, for a lower income woman), but with the effects highly localized in proximity to Metro stations.<sup>193</sup>

Examining the patterns of relative accessibility declines due to a hypothetical loss of different modes' availabilities provides a sense of the relative value of those modes to overall accessibility levels in different areas of the city. Figure IX-6, for example, shows the variation in effects of losing the bicycle option to a middle and lower income female, for both recreational and social accessibility. The maps reveal several interesting patterns. First, as already noted, lower income females suffer relatively larger declines when faced with losing the bicycle option. Second, considerable spatial variation can be detected in the apparent effects – both across trip purposes (within an income category) and across income categories. This variation comes from the combined effects of the relative attractiveness of other modes in those areas (e.g., walk, public transport) as well as the relevant land use distributions. The areas on the map with the darkest shading are those where a woman would be worse off, *ceteris paribus*, if the bicycle were removed from her mode choice set.

#### *IX.5.1.2 A Measure of Relative Automobile “Independence”?*

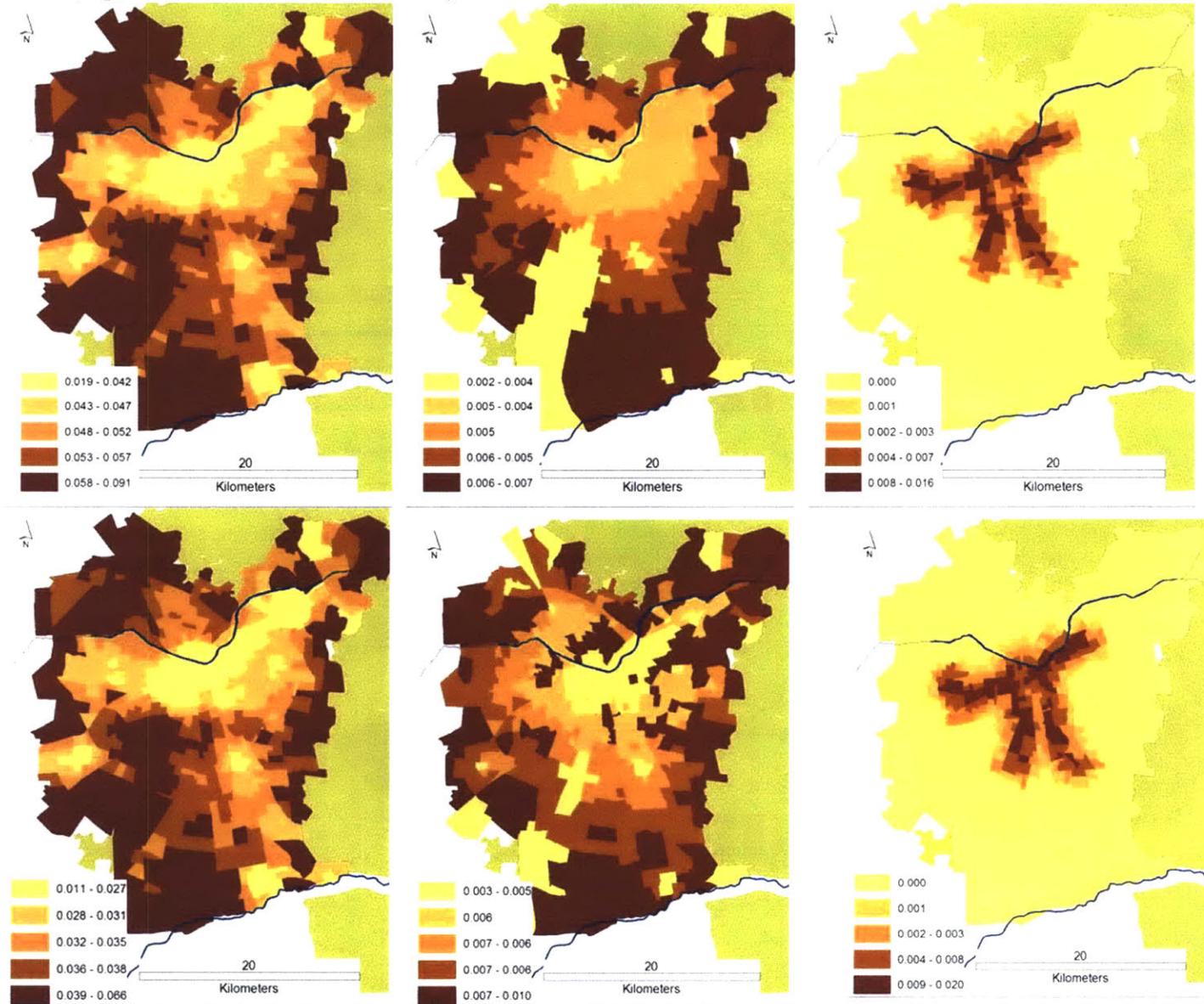
Extending the hypothetical reduction of the available mode choice set to the automobile reveals what might be interpreted as a measure of automobile “independence.” In other words, if one were to remove the automobile from the mode choice set from a given individual, where would she suffer the lowest relative decline in accessibility? This demonstration *does not intend to suggest the removal of the auto from the choice set as a viable policy option*; however, if we can fairly safely say that all else equal we would prefer less automobile use, where in the city would people be least affected if they had no possible auto use?

In this case, the relative effects on accessibility were averaged across the three income categories; that is, for each income category, the share decline was calculated in each zone and then the value was averaged. The results (see Figure IX-7) reveal interesting spatial variation, suggesting several areas of relative automobile “independence” (at least for recreational and social trips) in the city exist. Note that the relative declines do not necessarily have the same base, in other words two different areas might each decline by 3%, however, in absolute levels one area may still have significantly higher overall accessibility levels than another. To get a sense of those areas that have high total accessibility and low relative declines in accessibility with auto loss, one needs to compare Figure IX-7 with Figure IX-3 and Figure IX-4. Generally, we can see that the more central areas of higher accessibility also suffer the least when taking away the automobile option (the lighter shaded areas in Figure IX-7 represent areas of lower relative accessibility loss).

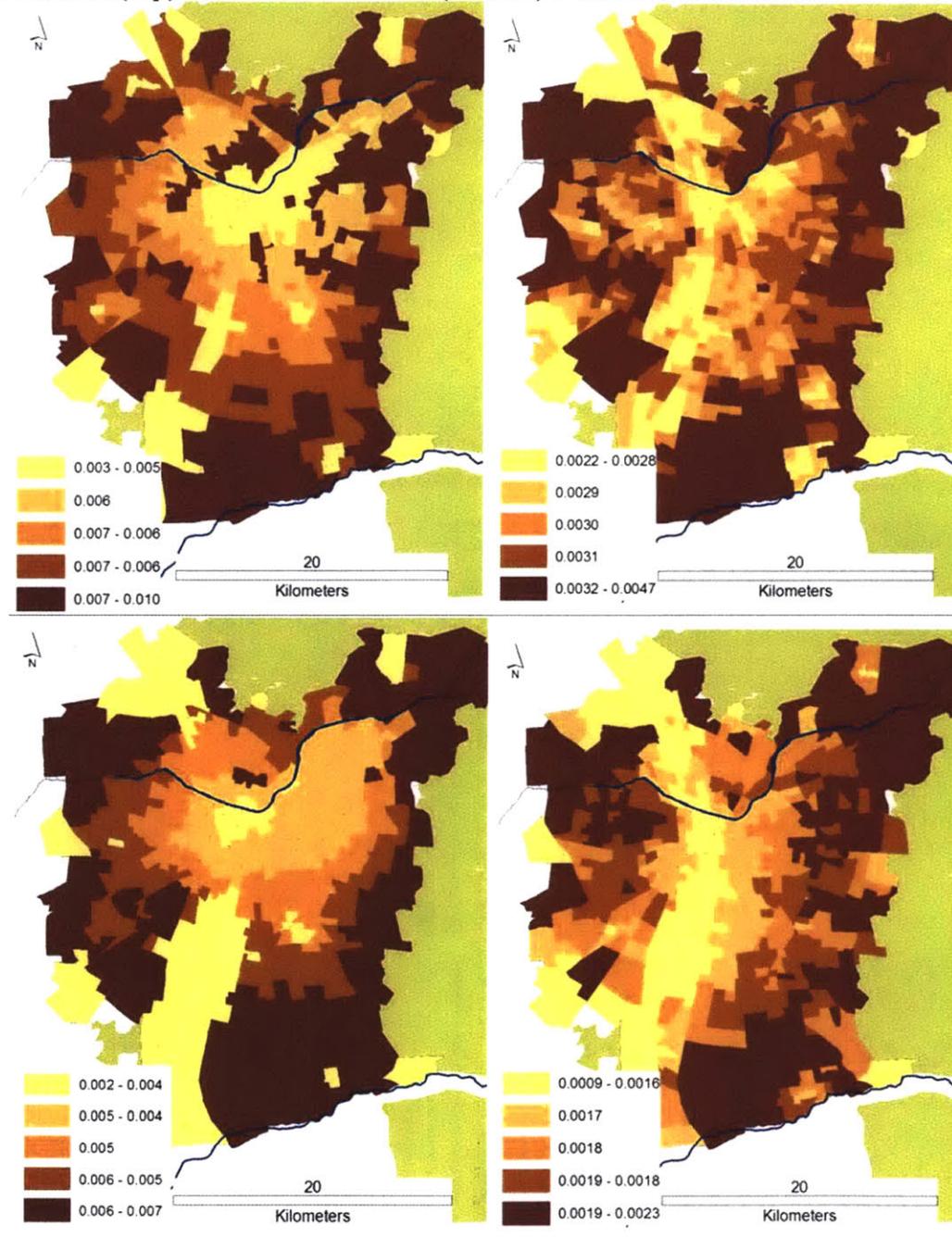
---

<sup>193</sup> Admittedly, this highly localized effect partly comes from the fact that inter-modal transfers were not modeled due to lack of necessary information.

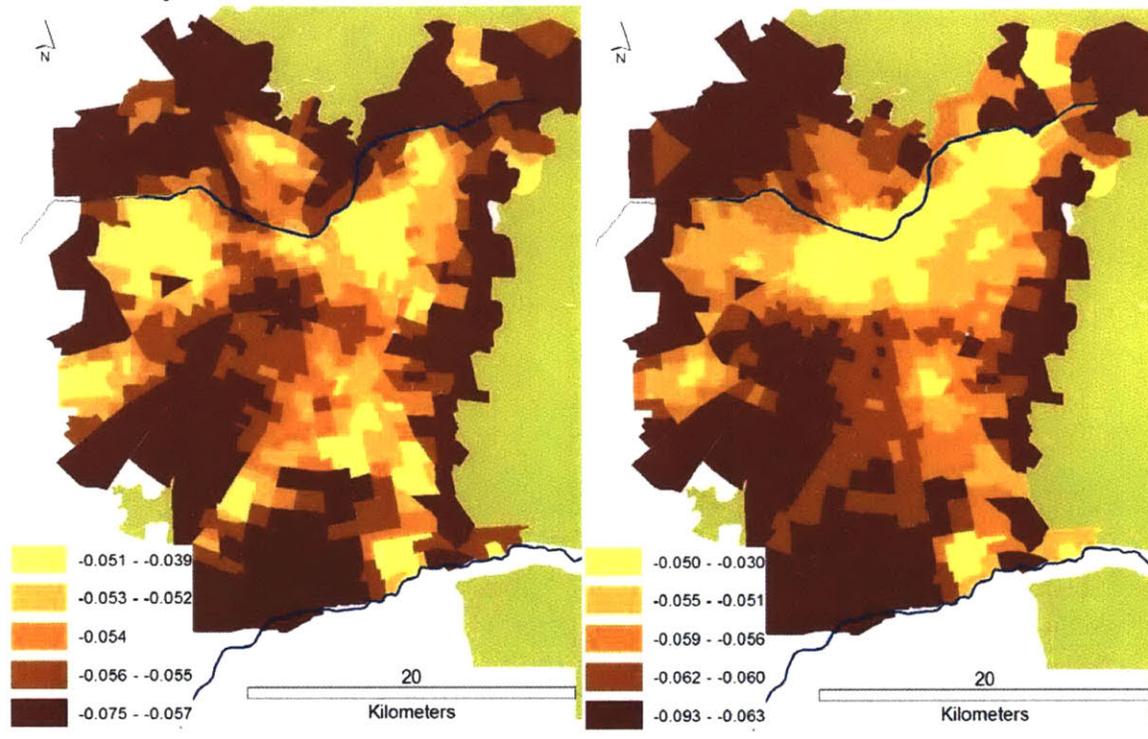
**Figure IX-5. Relative Decline in Recreational Accessibility Due to Loss of Auto (left), Bike (center), Metro (right): Middle Income (top) and Lower Income (bottom) Female**



**Figure IX-6. Relative Decline in Recreation (left) and Social (right) Accessibility for Low Income (top) and Middle Income (bottom) Female: Loss of Bike**



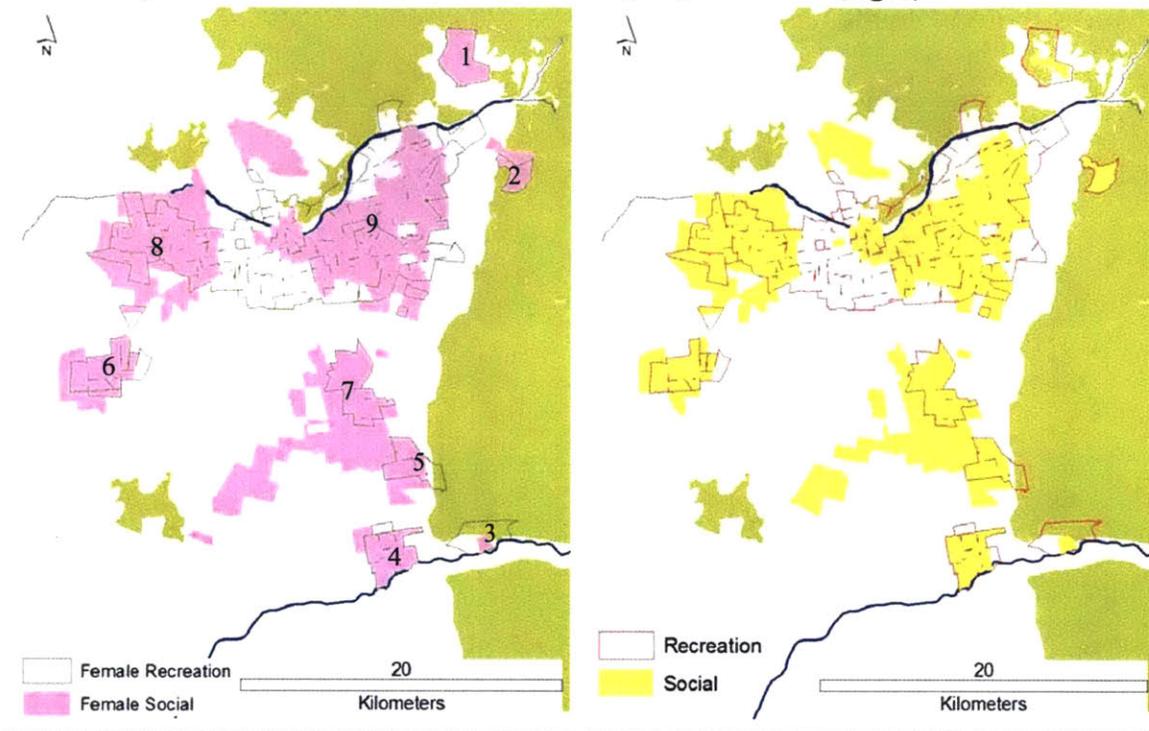
**Figure IX-7. Average Relative Decline in Social (left) and Recreational (right) Accessibility: Female Loss of Automobile**



In the case of low relative decline in social accessibility levels, at least three large swaths of the city can be identified: East, South and West of the CBD. In addition, several more distant “nodes” of relatively low loss can be seen on the Southern edge of the metropolitan area (Puente Alto), the Western edge (Maipú) and the far Northeastern foothills (Lo Barnechea). Notably, the former two also have relatively high accessibility levels for both low and middle income females (see Figure IX-3). For recreational accessibility, the largest contiguous area of least relative decline largely matches the Eastern skewed recreational accessibility pattern (from Figure IX-4). Again, however, several “nodes” of relatively low loss can be seen; a fair amount of overlap exists between these recreational “nodes” and the social “nodes.”

Figure IX-8 combines the areas of lowest relative declines in social and recreational accessibility, for both females and males. The maps show, for each trip purpose, the 20% of the city with the lowest relative declines. Note the strongly consistent pattern irrespective of gender and, in addition, the notable areas of overlap by trip purpose. These areas of overlap can be interpreted as the areas of highest *relative* automobile independence for social and recreational travel. Removing the auto from the choice set of people living in these parts of the city would impose the lowest relative declines in accessibility. As can be seen in the map, while areas with center city proximity do figure prominently in terms of relative auto independence, we also see multiple areas at considerable distance in each direction from the CBD. This suggests that both meso- and micro-level factors do play a role in relative accessibility levels.

**Figure IX-8. Areas with Lowest Average Decline in Relative Social and Recreational Accessibility after Loss of Automobile: Female (left) and Male (right)**



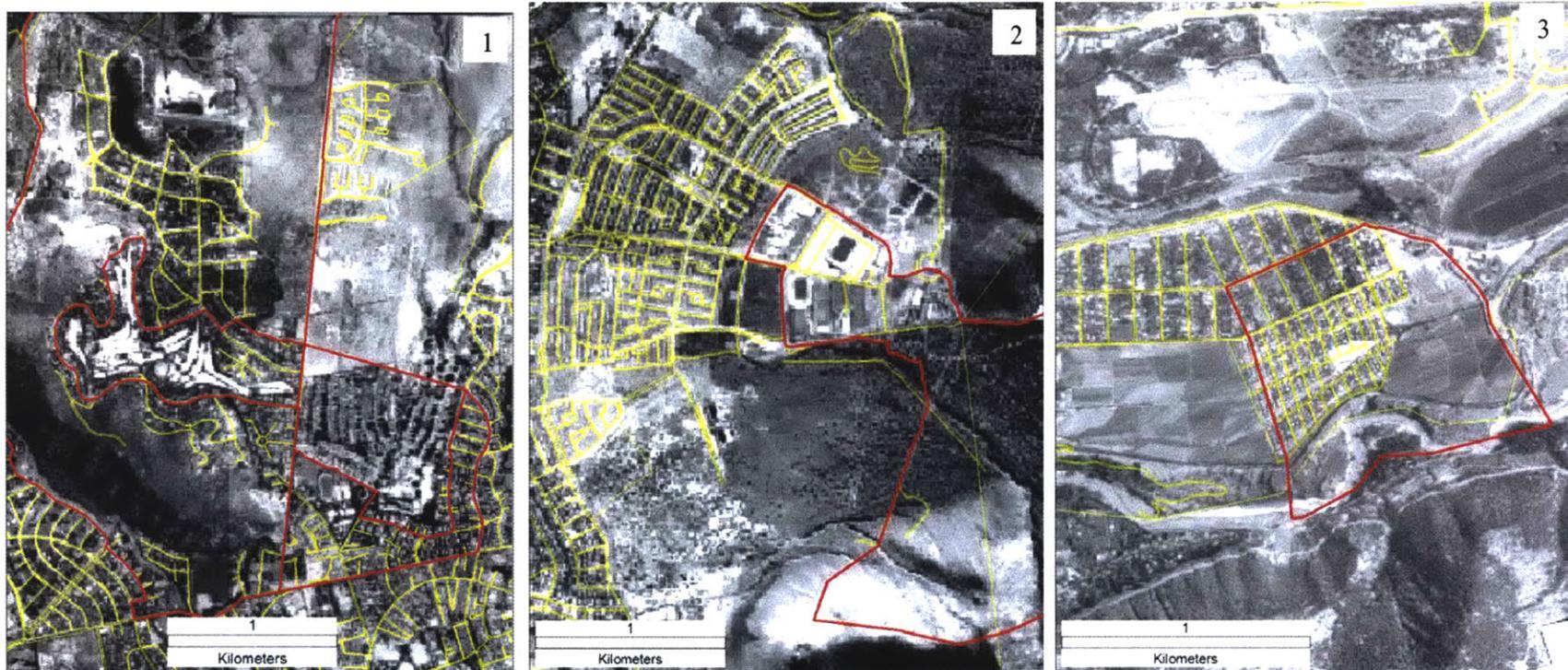
Upon closer examination, however, these areas of relative automobile “independence” do not, necessarily, share any obvious traits. Pooling the zones within the areas of overlap indicated in Figure IX-8 and comparing the average built environment characteristics in these pooled zones with those of the zones from the rest of the city reveals that the pooled zones have, on average,<sup>194</sup> a higher density of plazas and commercial and services, a higher number of 4-way intersections per road-kilometer, and a lower TAZ-average block equivalent radius (signifying a higher degree of urban fabric “porosity”). Of course, we cannot presume that these common characteristics lead to the relatively higher levels of automobile independence implied in this analysis. Perhaps more interestingly, as suggested somewhat by the relative locations of the different areas (labeled 1-9 on the left map of Figure IX-8) and confirmed in Figure IX-9’s close-ups, three different basic types of relatively auto-independent locations can be detected: (1) outdoor amenity-oriented, urban edge locations (1-3), in each case directly adjacent to or including sports clubs or other outdoor recreational facilities<sup>195</sup>; (2) dense residential suburban developments (4-6), characterized by small blocks on gridiron patterned streets<sup>196</sup>; (3) major urban sub-centers (7-9), with both 8 and 9 being long-consolidated areas of early urban expansion of the traditional CBD and 7 forming something of a “crossroads” of southern suburbanization.

<sup>194</sup> These differences were statistically significant (at 95% or greater) using a difference of means test. The “overlap” zones were treated as one sample and the rest of the zones were treated as another sample. All other built environment variables did not reveal significant differences between the two samples.

<sup>195</sup> In addition, not including potential destinations outside the study area in the destination choice set likely discounts the recreational accessibility afforded to these urban edge locations.

<sup>196</sup> Location 4 is, basically, the primary residential area of Puente Alto, historically a separate city from Greater Santiago; Location 6 is the primary residential area of Maipú.

**Figure IX-9. Close Up Views of Areas with Relative Automobile “Independence” for Social and Recreation Trips**



*This Figure continues on the following two pages. The numbers on each picture refer to the location in Greater Santiago, as indicated in Figure IX-8. The yellow lines on each figure denote the block boundaries (primarily streets) and the red lines denote TAZ boundaries. Note that the scales are not directly comparable across each picture. In all cases, North is up.*

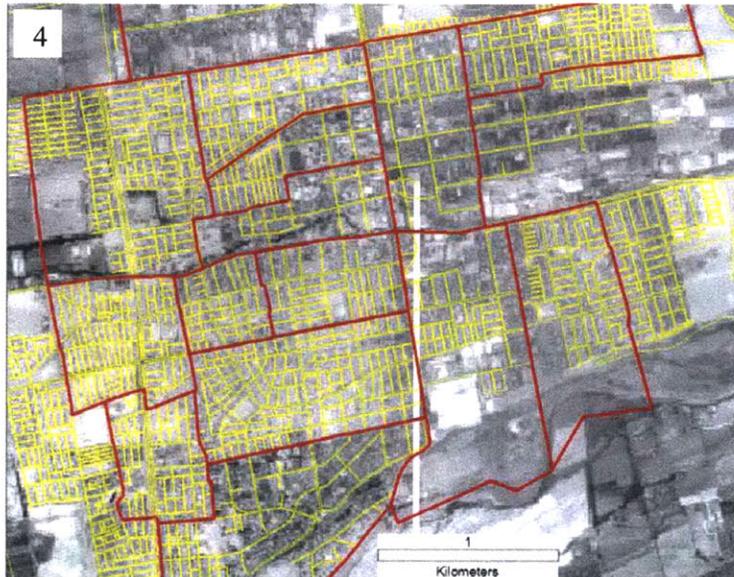


Figure IX-9  
(continued).

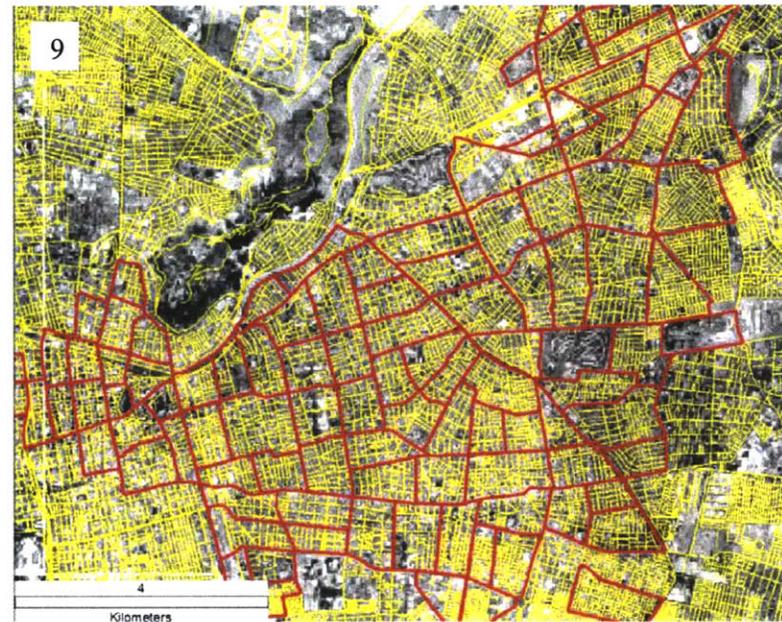
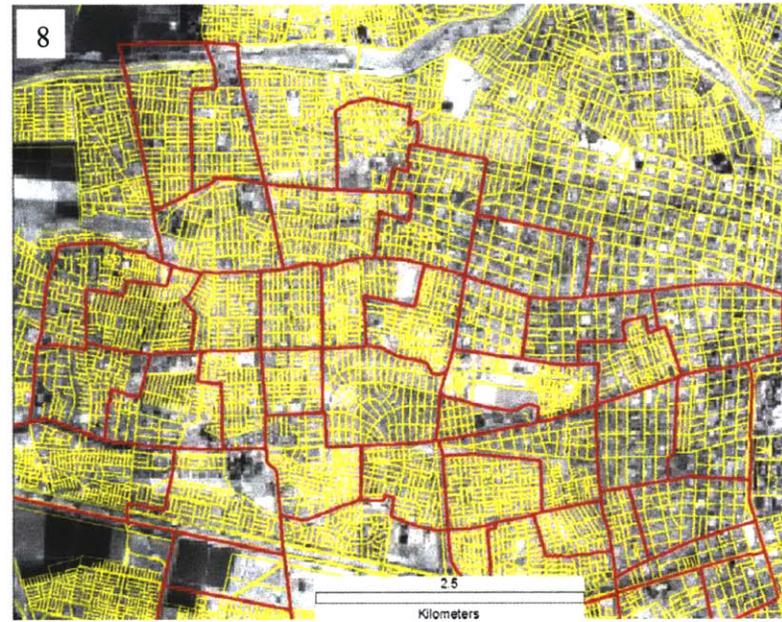
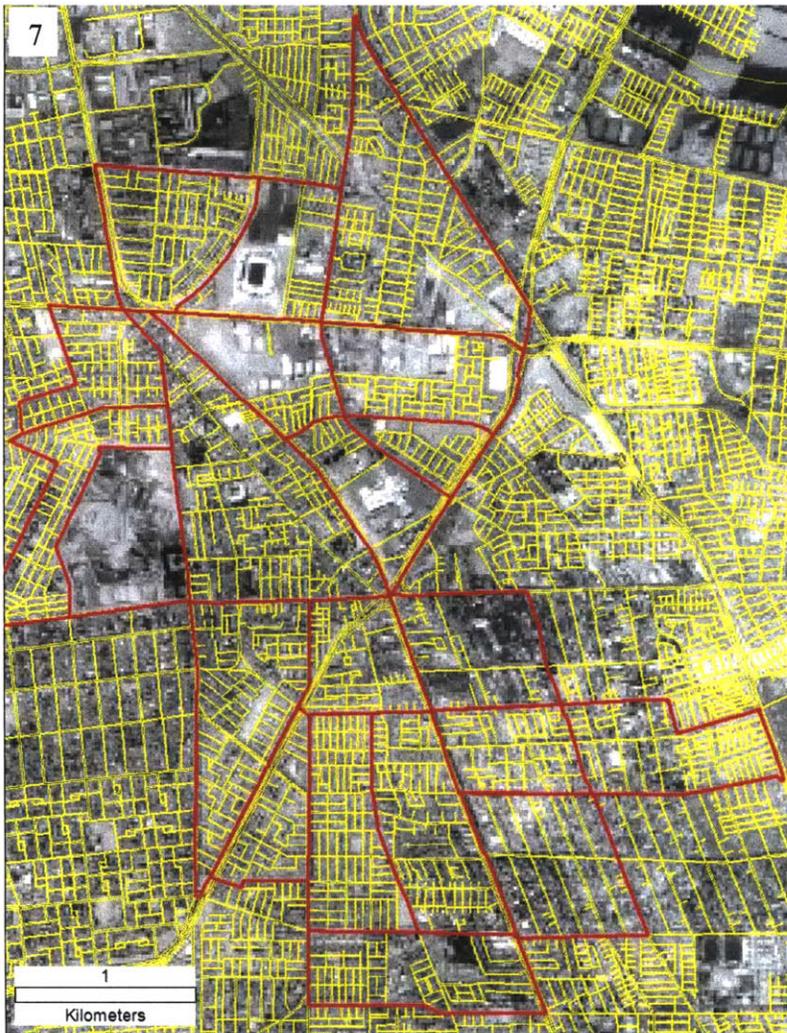


Figure IX-9  
(continued).

## **IX.5.2 Mapping the Sustainable Mobility “Trade-Off Space”**

The hypothetical elimination of modes from an individual’s choice sets suggests important spatial variation in impacts on relative accessibility. But, as proposed in Chapter III, the ultimate measure of relevance for sustainable mobility is accessibility per unit of mobility throughput. Here we explore that relationship spatially to gauge the influence, if any, of the built environment.

### *IX.5.2.1 Weighted Throughput*

The previous Chapter presented estimates of total annual passenger kilometers traveled as well as a simple proposed weighted form of passenger kilometers traveled, intended to serve as a proxy for mobility throughput in the sustainable mobility framework. This Section presents models of weighted PKT<sup>197</sup>, for the relevant subset of leisure trips. Following the basic approach in Section IX.3.1 (e.g., Table IX-6), an OLS model is specified, with the weighted PKT of the relevant trip purpose as the dependent variable, and several household, individual, trip-related, and built environment variables tested as explanatory variables. The approach suffers from some degree of non-transparency, in the sense that it does not reveal whether the effects on weighted PKT result from different modal choices, different distances traveled, and/or different occupancy rates (in this case, for private automobile travel and taxi travel, actual vehicle occupancy for trips originating from the same household were used<sup>198</sup>). Despite this shortcoming, as discussed earlier, from a sustainable mobility perspective, total relative mobility throughput – in this case proxied by the weighted PKT – matters most.

In the relevant estimations, the selectivity bias correction (for vehicle ownership; see Section IX.3.1) was not included. This was due primarily to a weaker theoretical justification – e.g., all PKT is included in the model, not just auto use. Other differences with the auto use estimations in Section IX.3 involve: the exclusion of vehicle-specific variables (since travel by all modes is included), the inclusion of individual-specific characteristics (mode availability; age), consideration of trip-specific characteristics (time of day, since each individual trip represents an observation), and variation in the types of built environment variables of influence. The final specifications were based on the best model fit from among a number of different tested variables.

Table IX-16 presents the results for visit trips and Table IX-17 presents the results for recreation trips. Overall, the results confirm expectations and, furthermore, indicate an apparent role of meso- and micro-level built environment influences on total weighted mobility throughput for both trip purposes. Interpretation of the results can be aided by a comparison to the relevant mode choice modeling estimates from the previous Section. For visit trips, household income plays an important role in individual trip weighted PKT;

---

<sup>197</sup> See Chapter VIII, Table VIII-6, for details on the method of deriving the weighted PKT.

<sup>198</sup> For details on derivation of shared auto and taxi travel by households, see footnote 184. There was no way to account for shared trips by people from different households, so occupancy levels are still likely underestimated. For auto passenger trips that did not have a matching household auto driver, the auto passenger’s weighted PKT was divided by two.

the effect is noticeably stronger for recreation trips, suggesting greater distances and mobility throughput intensity for these trips (which is consistent with the higher values of travel time estimated for recreation trips compared to social trips). The number of vehicles per driver in an individual’s household increases weighted PKT for both trip purposes, as does the availability of the auto drive option to the individual. On the other hand, bicycle availability to the individual has a significant negative effect on weighted PKT for both trip purposes. The traveler’s age increases the intensity of the expected mobility throughput. Regarding the trip-specific variables, these refer primarily to time of day, daily and seasonal variations; the implications of the results are not entirely intuitive. We see, for example, that weekend travel increases the mobility throughput for both trip purposes – this might reflect more time available to take longer trips. For recreation trips, the effect is somewhat dampened for summer Saturdays, likely reflecting increased bike attractiveness in the summertime (consistent with the mode choice models for recreation trips; e.g., Table IX-8).

**Table IX-16. OLS Model of Weighted PKT for Visit Trips**

Category	Variable	Beta	Standard. Beta	Std. Error	T-Statistic	Prob.
	Constant	-0.371		2.510	-0.148	0.883
<i>Household Characteristics</i>	HH Income (US\$ '000s)	0.372	0.078	0.109	3.402	0.001
	Vehicles per Driver	9.553	0.086	1.930	4.950	0.000
<i>Individual Characteristics</i>	Auto Drive Available	45.725	0.320	2.601	17.581	0.000
	Bike Available	-3.016	-0.026	1.225	-2.463	0.014
	Travelers' Age	0.223	0.073	0.032	6.932	0.000
<i>Trip-Specific Characteristics</i>	Weekend	8.314	0.071	1.204	6.906	0.000
	PM	-5.495	-0.044	1.329	-4.134	0.000
	Night	-10.426	-0.055	1.765	-5.908	0.000
<i>Urban Form</i>	HH Distance to CBD (kms)	0.779	0.064	0.142	5.501	0.000
	TAZ in Foothills	14.937	0.060	3.281	4.553	0.000
<i>Urban Design (Measured for HH TAZ)</i>	Avg. Block Equivalent Radius	0.050	0.051	0.015	3.372	0.001
	Diversity Index	12.338	0.023	6.139	2.010	0.045

Notes: the dependent variable is weighted passenger kilometer traveled per trip, derived according to the approach outlined in the previous Chapter. In this case, actual vehicle occupancy levels for private auto and taxi were used. N=7546; R-square: 0.21; F-statistic 168 (Prob. 0.0); standard errors are heteroscedasticity-consistent (using the White correction).

In terms of the meso- and micro-level built environment, we can see that with increasing household distance from the CBD, the mobility throughput intensifies; with further intensification due to locations in the foothills (consistent with the OLS estimates of household motor vehicle use; Table IX-6). For related micro-level (urban design)

characteristics, a larger average equivalent radius<sup>199</sup> of the blocks in a TAZ increases mobility throughput intensity as does the local diversity index. For social trips, the latter effect can be understood by the apparent negative influence of the local diversity index on the probability of walking for social trips; for the recreation trips, the source of the effects is not entirely clear. Finally, local park land has a small, but detectable negative effect on recreation trip mobility throughput.

**Table IX-17. OLS Model of Weighted PKT for Recreation Trips**

Category	Variable	Beta	Standard. Beta	Std. Error	T-Statistic	Prob.
	Constant	-2.810		2.562	-1.097	0.273
<i>Household Characteristics</i>	HH Income (US\$ '000s)	0.440	0.137	0.083	5.296	0.000
	Vehicles per Driver	6.100	0.063	1.346	4.532	0.000
<i>Individual Characteristics</i>	Auto Drive Available	33.542	0.280	2.700	12.422	0.000
	Bike Available	-5.889	-0.066	1.139	-5.171	0.000
	Travelers' Age	0.073	0.030	0.030	2.471	0.014
	Female	2.102	0.023	1.077	1.951	0.051
<i>Trip-Specific Characteristics</i>	Weekend	7.740	0.087	1.101	7.027	0.000
	AM	10.089	0.042	4.206	2.399	0.017
	PM	-2.952	-0.031	1.077	-2.742	0.006
	Late Night	19.970	0.080	4.464	4.474	0.000
	Summer Saturday	-0.002	-0.031	0.001	-3.165	0.002
<i>Urban Form</i>	HH Distance to CBD (kms)	0.488	0.049	0.143	3.417	0.001
	TAZ in Foothills	18.452	0.107	3.345	5.516	0.000
<i>Urban Design (Measured for HH TAZ)</i>	Avg. Block Equivalent Radius	0.051	0.048	0.024	2.144	0.032
	Diversity Index	12.713	0.030	6.330	2.008	0.045
	Density of Park Land	-0.001	-0.025	0.001	-1.990	0.047

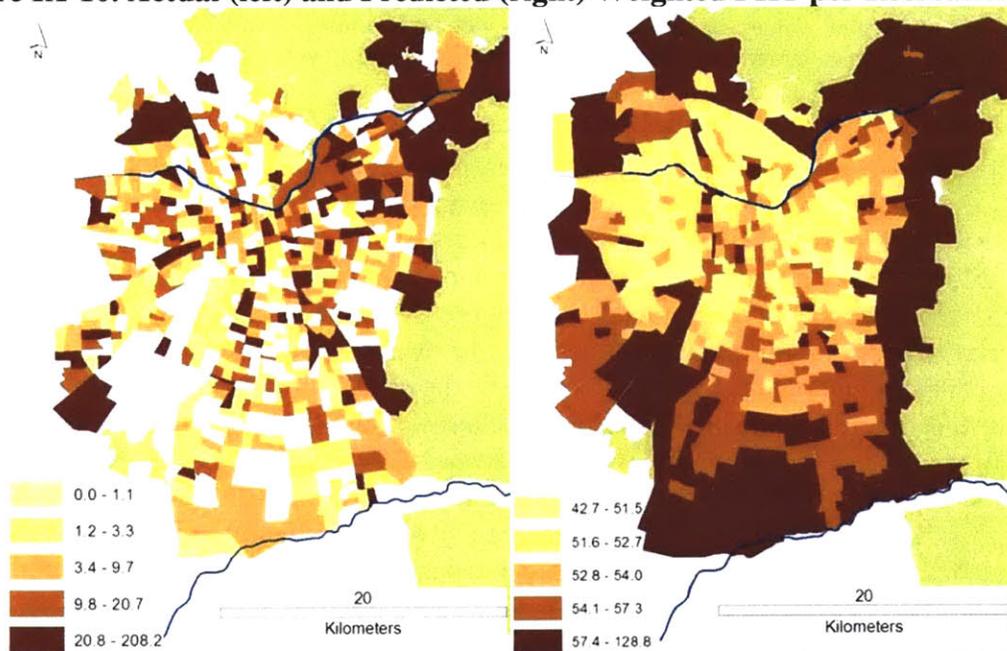
Notes: the dependent variable is weighted passenger kilometer traveled per trip, derived according to the approach outlined in the previous Chapter. In this case, actual vehicle occupancy levels for private auto and taxi were used. N=5436; R-square: 0.22; F-statistic 98 (Prob. 0.0); standard errors are heteroscedasticity-consistent (using the White correction).

The two models of mobility throughput (weighted PKT) serve to produce predicted weighted PKT levels throughout the city and then compare them to the relevant accessibility levels. In this sense, we need to keep in mind the relatively low explanatory power of these models, reflected in R-square values on the order of 0.21-0.22. While such

<sup>199</sup> Block equivalent radius is a proxy for porosity. It is calculated as:  $r = \sqrt{(\text{Area}/\pi)}$ , effectively converting the block size into an equivalent circle. A larger value signifies a larger equivalent radius essentially representing a less "permeable" urban fabric.

values are fairly high given the disaggregate nature of the models estimated, for the purposes of demonstrating mobility throughput variation across the city, only a few built environment variables will play a role; furthermore, almost 80% of the variation in mobility throughput remains unexplained by the model. Nonetheless, some predictive model is required in order to compare accessibility values across the city with expected mobility throughput. Actual throughput levels (i.e., those calculated directly from the survey), cannot account for the fact that social or recreational travel is not recorded for individuals residing in every possible zone in the city; furthermore, the actual levels do not allow the control for the relevant influencing variables (age, income, vehicle ownership levels, etc.). As such, we use predicted weighted PKT from the relevant trip purpose model to map the accessibility/mobility throughput trade-off space. Figure IX-10 and Figure IX-11 show the predicted versus actual weighted PKT for recreation and social trips. Looking at the predicted versus actual maps shows some amount of consistency between the two, despite the lack of controls on relevant variables of influence. For the predicted case, we can see the dominating effect of the distance to CBD; again, however, given the low explanatory power of the models underlying these predictions, the related maps should be viewed as very rough estimates.<sup>200</sup>

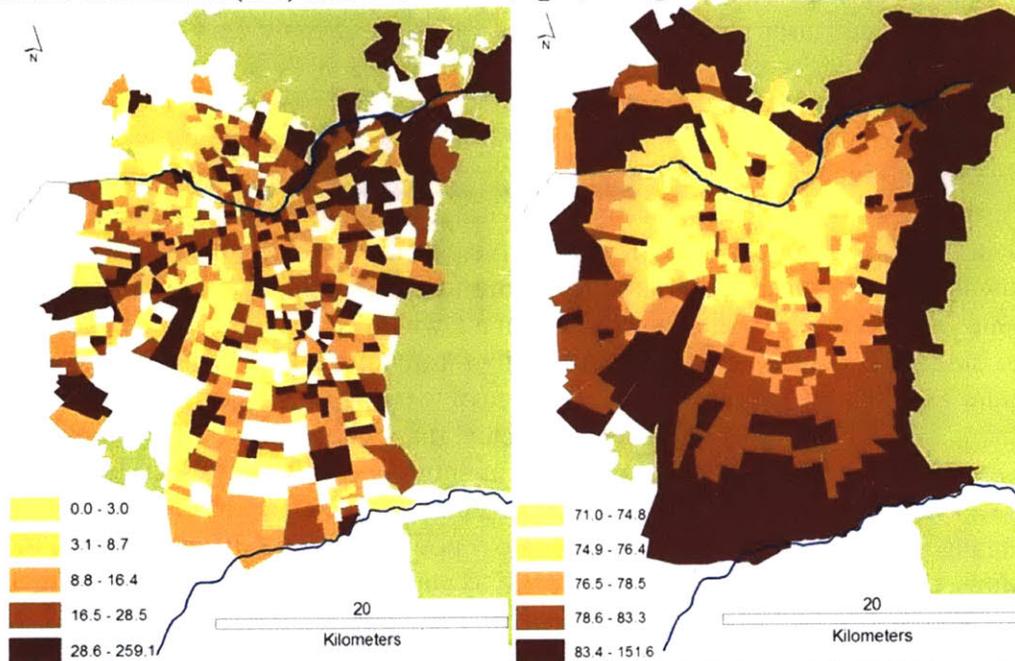
**Figure IX-10. Actual (left) and Predicted (right) Weighted PKT per Recreation Trip**



Note: In map of “Actual” values, white areas are zones with no information available. Predicted PKT based on average characteristics for a middle income, 35 year old male.

<sup>200</sup> Note that these predictions could be made more accurate using a fully calibrated travel forecasting model, capable of reflecting all trips and modes (i.e., including short trips and bicycle and walk trips).

**Figure IX-11. Actual (left) and Predicted (right) Weighted PKT per Visit Trip**



Note: In map of “Actual” values, white areas are zones with no information available. Predicted PKT based on average characteristics for a middle income, 35 year old male.

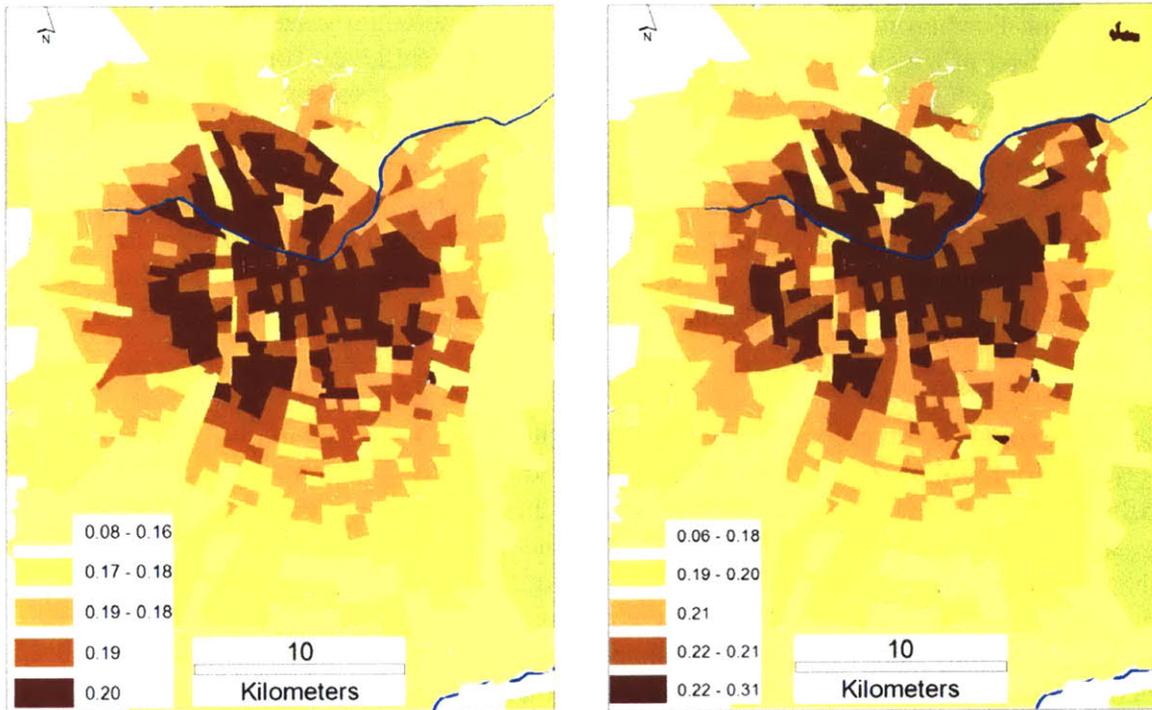
#### *IX.5.2.2 Areas of “More Sustainable” Mobility*

Using the base accessibility levels for a “representative” individual (i.e., those depicted in Figure IX-3 and Figure IX-4) together with relevant predicted mobility throughput measures (e.g., Figure IX-10 and Figure IX-11), we can devise a metric of “more sustainable” mobility and assess its spatial variation. To do so, a simple ratio is measured for each zone: accessibility/weighted PKT. Figure IX-12 presents a map of the resulting ratio for a 35-year old, middle income female (the overall patterns are basically consistent across gender and income categories). As can be detected from the maps, in which darker colors reflect “more sustainable” mobility, a relatively high CBD-orientation of the ratio exists. In the case of recreational travel, an eastward skew is evident, reflecting in part the higher recreational accessibility levels in the East. Furthermore a distant eastern “outpost” of fairly high sustainable mobility can be detected, well into the foothills; this area matches the area of relative automobile independence seen in Figure IX-8 and Figure IX-9.

Figure IX-12 suggests that both micro- and meso-level influences play a role in influencing sustainable mobility in Santiago, even though the result needs to be viewed cautiously, particularly in light of the large share of variation in weighted PKT (mobility throughput) that is not accounted for in the predictive model. While the predominant influence of the CBD cannot be denied, the results depicted in the map suggest some micro-level, urban design influences also play a role. Support for the suggestion of a micro-level influence also comes from the mode choice model (for visit trips), in which both the diversity index and dwelling densities influenced mode choice (thus relative utilities and the logsum accessibility metric), and from the weighted PKT model which

also showed the influence of urban design variables on both recreational and social trips' total mobility throughput.

**Figure IX-12. Accessibility-to-Weighted PKT Sustainable Mobility Ratio: For Social (left) and Recreation (right) Travel by a 35-Year Old Middle Income Female**



Similar to the case of the areas of relative automobile independence, no obvious traits, beyond relative proximity to the city center stand out in terms of specific local-level characteristics which make for “more sustainable” mobility.<sup>201</sup> One way to get a sense of what might be setting the better performing zones apart is to look at the 40% of the zones with the highest relative levels of sustainable mobility (the two darkest shaded zones in Figure IX-12). Pooling these 40% “best-performing” zones and comparing them to the rest of the zones of the city provides some basic evidence.<sup>202</sup> For visiting trips, on average, the zones of more sustainable mobility (beyond the obvious higher proximity to CBD) have a lower density of land dedicated to plazas, a higher concentration of commercial and services, lower dwelling unit densities, higher block “porosity” (measured by either equivalent radius or area/perimeter), a higher number of intersections per road-kilometer, and a lower share of dead ends per road-kilometer. In the case of recreation trips, all of the same significant differences appear, with the exception of plaza density. For recreational trips the zones with high relative measures of sustainable mobility have a higher average plaza density than the rest of city.

<sup>201</sup> The corridor of low sustainable mobility just west of the CBD contains the Panamerican Highway.

<sup>202</sup> Again, similar to the approach from the previous section, a difference of means test was performed. The differences reported here these differences were statistically significant (at 95% or greater) using a difference of means test. The “overlap” zones were treated as one sample and the rest of the zones were treated as another sample. All other built environment variables did not reveal significant differences between the two samples.

In short, then, we see that the built environment, at both the meso- and micro-level scales appears to influence sustainable urban mobility, at least for the subset of leisure travel trips considered here. We have seen, however, that the results should be interpreted as tentative, particularly in light of the need for more effective predictive models of mobility throughput. Furthermore, we need to keep in mind that potentially sustainable mobility for this subset of trips may well be counteracted by different levels (of accessibility and mobility throughput) when additional trip-making (e.g., work, school, shopping) is accounted for. Finally, while the research presented here has shown that local-level built environment characteristics are apparently associated with more sustainable mobility outcomes (for this trip subset), it has only indicated where, in general the preferable areas seem to be; further research could focus on identifying more specific characteristics of these areas which might lead to more concrete policy prescriptions. The final Chapter discusses these and other possible future research avenues.

## **IX.6 Conclusions**

This Chapter set out the goal of answering the questions “what role might Santiago’s built environment play on personal travel behavior and what, ultimately, might be the influence on sustainable mobility?” To answer these questions, we started at one of the most basic factors influencing individual and household travel behavior, private motor vehicle ownership. Via estimation of a multinomial logit model of household vehicle choice, we saw that – as might be expected in a city undergoing rapid economic growth and motorization – that at least one vehicle seems almost a certainty as soon as household income allows. As the household considers additional vehicles, however, meso- and micro-level land uses, as well as relative transport levels of service, apparently influence the decision. Increased local land use mixes, dwelling unit densities and proximity to the central business district decrease the probability of additional vehicle ownership, as does improved bus levels of service relative to the auto. One basic implication of this result is that authorities should include spatial variables and transport levels of service in motor vehicle ownership models in order to improve the accuracy of travel forecasting and, ultimately, the relevant policy and investment decisions.

To gauge the cascading effects of vehicle ownership on household vehicle use – an important component of mobility throughput (and, in turn, sustainability) – we turned to an ordinary least squares model predicting household automobile distances traveled (on the day of the survey). The expected influence of household income and the role of the number of vehicles in the household (controlling for selectivity bias) was shown. Again, significant meso- and micro-level built environment influences were also detected. Some support for the idea of the “compact city” can be found in the significant effect of household distance to the CBD. Furthermore, the evidence suggests that households living close to Metro stations do use their vehicles less (perhaps up to 4 kilometers per day less, on average), lending support for the idea of transit-oriented development as a means of reducing auto travel. In terms of local-level urban design effects, local street network and public space provision also exerted a significant influence on vehicle use. This evidence also implies potential gain from incorporating local level built environment factors into travel forecasting efforts.

Finally, to directly assess the potential influence of the built environment on sustainable mobility, the framework and metric proposed in Chapter III were implemented for a specific subset of travel purposes: social (visit) and recreation trips. This trip focus came from both practical concerns (reduced modeling complexity) as well as the fact that such trips: have not been modeled in great detail previously; already account for an important share of mobility throughput; and will likely be among the most rapidly increasing trip type with continued income growth. To derive an accessibility measure for these trip purposes, nested logit models of destination and mode choice were specified and estimated.

The modeling approach itself yielded interesting results. First, different mode choice modeling specifications for each trip type proved to provide the best model fit, suggesting the need to treat different trip purposes differently in future modeling efforts. Second, the models revealed, in general, that people tend to have a higher value of travel time for recreation trips, then social/visit trips, a reasonable result given the most likely more constrained time associated with recreation activities (e.g., getting to a movie on time). Of course, the higher than expected values of time returned by the models suggest that these results should be viewed tentatively. Third, for social trips anyway, local-level built environment effects do influence the probability of choosing walk and public transportation. As regards the nested destination-mode choice decision structure, the model indicates that, for leisure trips, a *Santiaguino* seems to view all of the places that s/he can go by a particular mode, such as auto or bike, as more similar than the different potential destinations. In other words, the decision process for the typical resident seems to be “I have a car, where am I going?” instead of “I am going to the park, how will I get there?” This may be interpretable, in some way, as a form of modal dependency.

Finally, to assess the spatial variation of sustainable mobility and the influence of the built environment, the accessibility measure derived from the nested destination-mode choice model was combined with a predictive model of weighted passenger kilometers traveled (intended as a proxy for mobility throughput). In terms of the accessibility measure itself, a fairly strong CBD-focus was found; not surprisingly, the results suggest severe inequalities in accessibility across income groups. Furthermore, the loss of the automobile option diminishes the accessibility for an average adult by considerably larger amounts and for much larger areas of the city than would the loss of the bicycle or Metro option. The idea of removing the automobile from the adult traveler’s choice set was further extended, as a means of indicating areas with relative automobile “independence.” These areas would suffer *relatively* less if, for leisure travel anyway, the auto option was no longer available. Several different areas were identified, including several on the urban edge, associated primarily with large recreational amenities. Finally, the sustainable mobility “trade off” space was mapped, indicating that, indeed the center of the city and areas of relative proximity seem to produce the most sustainable mobility outcomes (for this trip subset). Some evidence of micro-level influences exist, possibly associated with block size and shape, street network type, and several land use types. A key avenue for future research would be to identify with more resolution whether

particular neighborhood types might be associated with these outcomes. The final Chapter discusses this and other directions for future research.

# X

## CONCLUSIONS AND IMPLICATIONS

This dissertation has attempted, through a long and somewhat winding journey, to answer a fairly straightforward question: does the built environment play a role in sustainable urban mobility and, if so, what role? Answering this somewhat simple question ends up being a challenging enterprise. No clearly laid out, broadly accepted definition of sustainable mobility exists. Furthermore, the influence of the built environment on travel behavior remains a research realm rife with wide-ranging results and few clear, generalizations with direct policy relevance. This Chapter reviews the process that led to a tentative answer to the basic research question. In doing so, the Chapter structures the discussion in three basic categories: (1) the proposed theoretical sustainable mobility framework; (2) the analytical methods employed to “measure” sustainable mobility and measure the influence of the built environment; and, (3) implications for policy and planning in Santiago and other cities. Finally, the Chapter ends with a summary of the strengths and shortcomings of the research presented and offers ideas on future research areas.

### **X.1 Sustainable Mobility: The Theoretical Framework**

Chapters II and III derived the analytical framework and associated indicators proposed for “measuring” the concept of sustainable mobility. We saw, in the brief review of the sustainability concept, that the idea can be traced far back to the early days of natural resource management and economics. Today, the words sustainable development and sustainability have become commonplace and, in, some sense, nearly trite, taking on so many dimensions and meanings that some might say that they have become almost meaningless. In part, this derives from the complexity of the sustainability concept and the lack of a common definition and common means of measurement. In that regard, a return to the basic Brundtland definition – “sustainable development meets the needs of the present generation without compromising the ability of future generations to meet their needs” – seems warranted. Sustainable development poses the fundamental challenge of balancing the needs of today with the needs of the future.

The Brundtland definition lends itself to a straightforward re-characterization, in basic economic terminology, of sustainable development as development that *maintains the capacity to provide non-declining per capita utility in time* (following Neumayer, 2003a,b). While tractable and lending itself to some degree of measurement, this definition still faces unresolved issues. For one, it leaves open the issue regarding whether or not current utility levels are satisfactory (which may be of particular concern in developing countries). Perhaps more fundamentally, however, the definition depends on perspectives regarding the utility-providing capacity – i.e., capital. Essentially, two basic and opposing “schools of thought” can be identified:

- the technological optimists, who essentially believe in the substitutability of natural capital by human-made capital (aided by continuous technological evolution) – the so-called “weak sustainability” paradigm; and,

- the natural resource advocates, who essentially believe that (at least) certain fundamental natural capital functions cannot be substituted for by human-made capital – the so-called “strong sustainability” paradigm.

As Neumayer (2003b) makes clear, both the weak and the strong sustainability paradigms are (at present, anyway) non-falsifiable. As such, both schools of thought depend on the strength of their underlying assumptions and belief systems. The idea of sustainable development then, even if we accept the basic definition, remains an intellectually contentious proposition, depending ultimately on our values and prevailing belief systems. How do we value future generations and what we leave to them (related to, e.g., discount rates)? How do we value “non-economic” resources? How do we value the distribution of resources among current generations? The inherently value-laden responses to these types of questions at least partly explain how sustainability has, as I suggest, come to mean “all things to all people.” Does sustainability really offer a new concept, or simply new language for various (and often strongly conflicting) interpretations of the idea of the “good society” that have existed, most likely, for all humankind?

These questions remain completely pertinent when we turn to sector-specific considerations of sustainability. The urban setting proves no exception. In fact, in exploring the ideas of sustainability as they have been applied to urban planning and development, I make explicit links to the most notable philosophies that have, arguably, dominated (explicitly or implicitly) city planning during the past Century: modernism and post-modernism. Ignoring the multiple and non-trivial variations in the interpretations of these philosophies, I conclude that the idea of the sustainable city or sustainable urban development rests in a modernist/post-modernist synthesis space: sustainable urban development is often depicted in a post-modernist way (e.g., implying holistic, participatory approaches, “human scale” interventions, etc.); the pursuit of sustainable urban development, however, represents a basic modernist endeavor (i.e., shaping the city to improve society in a measurable way). Again, the fact that sustainable urban development inevitably rests on the prevailing value system leads us to the conclusion that the sustainable city really just means the “good city.” Indeed, the principles commonly underlying the sustainable city idea were shown to map directly to Lynch’s (1984) theory of “good city form,” building on ideas of justice, efficiency, vitality (including concerns for future generations), access, etc.

### **X.1.1 Sustainable Mobility: An Operational Definition**

Finally, narrowing in specifically on the transportation sector, I traced the evolution of the sustainability concept. First formally developed and applied in the wake of the 1987 Brundtland report (e.g., Replogle, 1987), the ideas of sustainable transportation soon took on the broader sustainability dimensions and became mainstreamed by organizations such as the OECD, the European Union, and the World Bank. Despite the fairly common rhetoric across the multiple studies, analyses and research efforts, no agreed-upon operational definition of sustainable transport can be found. Once again, we can see that the term, in many ways, has been taken to mean many things to many people, or, possibly, all things to all people. What is sustainable transport? It is “good” transport.

But the idea of “good” transport, of course, varies by individual and, thus, depends on beliefs and values. Cynically, one might view some of the sustainable transportation initiatives as opportunistic attempts to maintain the status quo, or further entrench current transportation patterns, such as the World Business Council’s proposition that sustainable mobility starts with “access to means of personal mobility” (WBCSD, 2004). The various studies reviewed in this research were found to often confuse definitions with principles, goals, objectives, and/or prescriptions.

Furthermore, with the growing importance of “performance-based” transportation planning (Meyer and Miller, 2001), countless efforts have been made to develop indicators of sustainable transport (e.g., Lee et al, 2003; Jeon and Amekudzi, 2005). Sustainable transport has in some sense turned into a measurement game, with efforts to measure, for example, pollution, accidents, etc. Without trying to belittle the importance of understanding the multiple impacts (positive and negative) of transportation, I argue that the pursuit of measurement without a clear definition of *why* we are measuring what we are measuring or with no clear understanding of what we mean by sustainable transport or sustainable mobility is fruitless, at best, and counter-productive at worse. In short, we need an operational definition of sustainable mobility.

With specific reference to the passenger side of transportation, I propose an operational definition of sustainable mobility as *maintaining the capability to provide non-declining accessibility in time*. This definition derives directly from the broader sustainable development definition above. Two words are emphasized in the proposed definition. Accessibility essentially represents the welfare (or utility) that people derive from the transportation (and land use) system. The emphasis on capability comes from the fact that we cannot know what levels of accessibility future generations will desire; at a minimum, we should provide them with the capability to achieve the levels that we enjoy today.

Accessibility represents that which the mobility system provides: access to daily needs and wants that allow people to survive and thrive. Such measures have a long history of use as social and economic indicators (see, e.g., Wachs and Kumagai, 1973) and the term accessibility appears in several definitions of sustainable transportation (e.g., WBCSD, 2001; OECD, 2002; CST, 2002). Furthermore, the idea of accessibility, as the enabler of human capital development, links directly to the key sustainable *development* priority of developing countries; priorities which Sen (2002) eloquently elaborates on within the sustainable development debate and which relate straightforwardly to his idea of “development as freedom” and related concepts of “functionings” and “capabilities” (e.g., Sen, 1998).

What about the *capability* to provide accessibility and, particularly, the need to maintain this capability *in time*? I argue that this capability can be thought of in terms of stocks: the natural, human-made, and social/institutional stocks that enable the mobility system to function. More precisely, accessibility (to employment, education, recreation opportunities, etc.) increases the stock of human capital, but, in doing so, it depletes other capital stocks. The rate of that depletion depends on *mobility*. In this way, sustainable mobility can be thought of as a balancing act between the desire to expand accessibility

(which builds human capital) and the need to maintain capital stocks. This proposed *operational* definition of sustainable mobility does not lend itself to an absolute measure of sustainability. Rather, the definition establishes a *normative* framework which allows us to make relative judgments regarding sustainable mobility. In short, *a more sustainable mobility system provides more welfare (utility) per unit of throughput (capital drain)*, with welfare measured by accessibility and throughput by mobility.

## **X.2 Sustainable Mobility: Towards a Methods of Measurement in the Urban Setting**

With the operational definition thus derived, Chapter III proposes a formal means of measurement. For measuring accessibility, among the various possible approaches, I suggest that utility-derived accessibility – derived from the discrete choice models in the random utility theory tradition - offers several benefits. First, being based on the individual’s actual choice set, utility-based accessibility can reflect individual preferences, thereby providing consistency with, for example, Sen’s “human freedoms” perspective. Second, with its derivation from discrete choice models – which have a long tradition of application in transportation system analysis (e.g., Ben-Akiva and Lerman, 1985) – utility-based accessibility measures can be somewhat straightforwardly developed from “off-the-shelf” analytical techniques. Furthermore, based in microeconomic behavioral theory, utility-based accessibility measures offer direct links to traditional measures of consumer surplus and user benefit (e.g., Williams, 1977; Small and Rosen, 1981).

For the “mobility throughput” side of the sustainable mobility “equation,” I propose that vehicle kilometers traveled (VKT) or passenger kilometers traveled (PKT) offers an effective proxy for mobility *throughput*. Vehicle use intensity reflects relative capital stock drains. Of course, the degree of capital drain ultimately varies considerably based on vehicle technologies, time-of-day of travel, occupancy levels, operational conditions, among many other influencing factors. I argue, however, that such variation can be accounted for within the basic VKT/PKT metric. From the “strong sustainability” perspective, the throughput metric might build from the “ecological footprint” approach, for example. In the “weak sustainability” tradition, the throughput metric might look to the transportation “full cost” analysis approach. In fact, with the latter approach, one could imagine an “estimable” sustainable mobility equation, converting the utility-derived accessibility metric into relevant currency units, from which the relevant “costs” could be deducted, moving towards “least cost,” “full cost” integrated transportation planning possibilities (e.g., Zegras and Birk, 1994).

In the end, I propose a straightforward mobility trade-off space, which allows for the detection of “more sustainable” outcomes. In this trade-off space, “more” or “less” sustainable situations can be assessed; *all else equal we want more accessibility with less mobility throughput*. Many factors could contribute to variation in the outcomes, including differences in the built environment. It is worth noting that this proposed trade-off space, accessibility versus VKT/PKT, is fully capable of taking advantage of the existing sustainability indicator initiatives, the products of which should fit within the accessibility or throughput dimensions.

### **X.2.1 The Role of the Built Environment**

In order to better understand the potentials for the urban built environment to influence travel behavior and, thus, sustainable mobility, Chapters IV and V reviewed and analyzed the related literature. The research in this continuously active field can be traced back, in the United States anyway, to at least the early 1950s (e.g., Carroll, 1952). In order to make sense of the results, Chapter IV presented an over-arching analytical framework (building from, e.g., RERC, 1974; Handy, 1996) within which roughly 80 studies were reviewed. The usefulness of the framework comes from: (1) its explicit consideration of scale of analysis – metropolitan-level, meso-level, and micro-level – and corresponding metrics of the built environment – relating to urban structure, urban form, and urban design, respectively; (2) differentiation according to analytic technique, with five different basic approaches employed and further variation based on the types of data employed (i.e., aggregate or disaggregate). This framework should provide a useful structure for situating future relevant analyses.

The multiple studies reviewed reveal somewhat wide-ranging estimates of effects. To some degree this variation, can be attributed to variations in approach (e.g., scale of analysis, analytic technique), the types of built environment measures used (and the means of their measurement), as well as the outputs (effects) measured, such as mode choice, trip rate, etc. Perhaps the most notable development in recent years has been the push to base the relevant research within more rigorous behavioral theories. Crane (e.g., 1996) should be, at least partially, credited with this push, which, after all, closely aligns with “traditional” transportation systems analysis (e.g., Ben-Akiva and Lerman, 1985). Most notably, recent years have seen relevant analysts make the explicit turn to discrete choice models (e.g., Srinivasan, 2000; Zhang, 2002; Rajamani, et al., 2003).

Ultimately, few generalizations are possible from this research review. At the Metropolitan-scale, drawing primarily from inter-city comparisons, there seems to be good evidence showing the link between total urban area and, *ceteris paribus*, total intra-city passenger travel (e.g., Cameron, et al, 2003). At the intra-metropolitan scale, factors such as the degree of urban poly-nucleation and relative distance to the central business district (consistent with the metro-level total urban area finding), seem to reveal consistent influences. At the micro-scale, however, the picture becomes murkier; local mixing and density does apparently influence mode choice, although the impacts on overall travel are basically indeterminate. Furthermore, in practice the micro-scale and meso-scale influences may not be truly separable; for example, local-level effects may have no influence without relevant meso-scale characteristics, while meso-level influences such as relative densities or mix of uses may only be possible with particular micro-level design characteristics (e.g., certain street widths and block sizes).

Several challenges remain within this field of research. One relates to the type of data typically used – trip-based household travel surveys for a single day (often a typical work week day). Data in this form make it difficult to assess broader travel impacts, including weekly shopping habits, recreational travel, and trip-chaining propensity. Perhaps more fundamentally, however, comes the problematic issue of “self-selection.” Self-selection refers to the fact that the related empirical work aims to measure individual and/or

household travel behavior under the assumption that the built environment influences that travel behavior; the possibility may well exist, however, that people/households choose their location based on the travel behavior they prefer and, thus, they “self-select” into those locations. Recently, the self-selection issue has been explored using panel data (i.e., surveys following the same households in time; Krizek, 2003c) as well as econometric corrections (e.g., Greenwald, 2003; Khattak and Rodriguez, 2005). These analyses find built environment influences on travel behavior, even after controlling for self-selection. Individual attitudes may also play an influencing, and difficult to capture role; in fact, Kitamura et al (1997) find attitudes to be the primary determining factor influencing travel behavior.

Finally, as reviewed in more detail in Chapter V, the relevant analyses vary considerably in how they actually measure the built environment. Here, challenges come from the difficulty in finding accurate measures that can reflect the item of interest (including, mix and complementarity of land uses), the potential distortionary effects from the modifiable areal unit problem (MAUP), and challenges to measuring influences which may be well work in concert (i.e., “the whole is greater than the sum of its parts”; e.g., Greenwald, 2003). In partial response to these difficulties, some researchers have taken a “quasi-experimental” approach, selecting neighborhood types, attempting to control for relevant influencing factors (e.g., meso-level location, socio-demographics), and then exploring travel differences. One benefit of such an approach rests in possible ease of translation of results to policy-makers and the general public (for example, by enabling presentation of *actual* development types, instead of effects from abstract built environment metrics).

### **X.3 Implications for Santiago**

Turning now, to the empirical case, in Chapter VI we saw that Santiago, despite rapid economic growth over the past two decades, continues to exhibit motorization rates that, relative to the industrialized world, lean much closer to the dense Asian cities than Europe or North America. Somewhat surprisingly, perhaps, this comparatively low motorization rate seems to hold relative to Santiago’s “peer” cities as well.<sup>203</sup> In the latter case, it is not clear whether the apparently lower motorization comes from vehicle costs (due to, perhaps, stricter vehicle emission standards and/or restrictions on used vehicle imports<sup>204</sup>), income distribution and relative purchasing power across all households (e.g., Gakenheimer, 1999), Santiago’s built urban environment, and/or other factors (including data quality differences across the cities).

At the same time, Santiago, and Chile more generally, continues to experience sustained economic growth, bringing concurrent motorization and urban development pressures. In some ways, the Chilean economic “success” of the past 15 years has made it something

---

<sup>203</sup> National-level comparisons reveal the same conclusion (World Bank, 2002; p. 10).

<sup>204</sup> The lack of a domestic automotive industry (unlike, e.g., in Brazil and Argentina) may play a role also. In terms of used vehicle imports, the fact that the three Chilean cities exempted from used vehicle customs duties (Iquique, Punta Arenas, and Arica) have notably higher household auto ownership levels supports conclusion of a dampening effect – on national-level motorization – of used vehicle restrictions relative to neighboring countries, like Perú.

of a model for other developing countries in the region and elsewhere.<sup>205</sup> Chile has been at the forefront of economic liberalization, which among other things has included disciplined macro-economic policy, pension reform (privatization) and an aggressive infrastructure privatization program, including for highways and other transportation infrastructure. In some ways, then, Santiago, the city, may well offer lessons to other cities in the region – at least cities of comparable size or quickly moving in that direction. While Santiago dwarfs her nation’s other cities in terms of size, the possibilities that the analysis in this dissertation may offer lessons for other Chilean cities should also not be discarded.

### **X.3.1 Santiago: *Quo Vadis?***

From the analysis of Santiago’s built environment presented in Chapter VII, we can conclude that Santiago shares some basic built environment and transportation characteristics with US cities from the early 1960s. In fact, today’s Santiago displays basic urban structure, demographic, and travel traits similar in some ways to metropolitan Chicago in the late 1950s (see Table X-1). Even at that time, however, Chicago manifested higher vehicle ownership, considerably higher auto mode share, and (perhaps partly as a result) greater estimated trip distances and more dispersed metropolitan development patterns. Chicago’s high motorization rate reflects the fact that by the late 1950s, the U.S. had already experienced a 40-year history of intense motorization. Indeed, national per capita motor vehicle levels in the U.S. in 1931 already exceeded Santiago’s 2001 levels (Todd, 1960). This latter point likely reflects influence of governmental policies (e.g., U.S. auto industry promotion), settlement structure, as well as average household income levels and income distribution.<sup>206</sup>

Broadly, then, we can say that while Santiago today and Chicago circa 1960 share some physical traits, a primary difference in the two cities relates to household income levels and motorization rates.<sup>207</sup> Does an urban area like the Chicago Metropolitan Area (CMA) offer a possible reference point as to where the Santiago Metropolitan Area (SMA) might go in the future? If the SMA’s population grows at 1.4% per year,<sup>208</sup> it will have 7.6 million inhabitants by 2030, compared to 7.2 million for the CMA area in 1990. At current growth rates in households, persons per household, and household income, the SMA in 2030 would have nearly the same number of persons per household as the CMA in 1990 (2.7 for Chicago versus 2.5 for Santiago), and comparable average household

---

<sup>205</sup> Note, I am not advocating the Chilean “model,” per se, rather just pointing to the fact that the Chilean neo-liberal economic development paradigm has been widely touted by development agencies such as the World Bank. The reference to “model” here also comes with full recognition of the political sensitivities in the region; that is, many countries (or, at least, not insignificant shares of their populations) in the region view Chile and its model with skepticism, or even antagonism.

<sup>206</sup> In 1960, the US Gini coefficient was 0.36, compared to 0.50 in Santiago; in 1959, U.S. median family income (in US\$ 1999) was \$27,000 compared to Santiago’s mean of (in US\$2001) \$10,000 (US Census Bureau, 2004, 2005).

<sup>207</sup> Also, the cities differ considerably in terms of rail-based infrastructure; at the time, Chicago had 11 suburban rail lines and 7 mass urban transit (subway) lines.

<sup>208</sup> Equal to the growth rate between the 1992 and 2002 Censuses and, most likely a high rate for future population growth given the general trend of declining growth rates: 2.6% from 1970-1982; 1.9% from 1982-1992.

income levels, US\$36,000 for Chicago versus \$37,000 for Santiago.<sup>209</sup> Note, however, that the SMA figure is estimated mean household income, while the figure for the CMA is the *median* household income. The distinction is important because of the implications for income distribution and continued growth in the middle class. These, in turn, will play an important role in overall motor vehicle ownership levels (as suggested, e.g., by Gakenheimer, 1999) and will also play an important role in urban development patterns (including demand for space, suburbanization desires). Indeed the interaction of these three key factors – household income growth, motor vehicle ownership, and patterns of residential space demands – and authorities’ interventions via infrastructure investments and urban planning and management will, essentially, dictate the future structure of the SMA.<sup>210</sup>

**Table X-1. Chicago (1956) and Santiago (2001): Basic Indicators**

Indicator	Chicago (1956)	Santiago (2001)
Population	5.2 million	5.6 million
Persons per Hectare	17-110 ( <i>net</i> )	60-90
Urban Area Dedicated to Freeways	2.8%	2.1%
Households with no Automobile	~35%	57%
Autos per 1000 Persons	260	140
Autos per Household	0.83	0.5
Drivers Licenses per 1000 persons	389	254
Drivers Licenses per Household	1.25	.99
Trips per person	1.7	2.4
Average Trip Distance (kms)	8	5.5
Auto Mode Share	71%	27%
Public Transport Mode Share	27%	35%
Walk Mode Share	2%	27%

Source: Chicago data from CATS, 1959; Levinson and Wynn, 1963.

Notes: Levinson and Wynn report the net (high end) population density for Chicago, while the low end covers the entire study area (>1200 sq. miles) (CATS, 1959). The Santiago’s population density range comes from different considerations of overall urban land area (particularly relatively undeveloped areas on the urban fringe). The high end of the range can be interpreted as a rough measure of *net* residential density; it is calculated as the mean for *populated* blocks from the 2002 Census; strictly speaking this is not a net density measure, which should be calculated for actual residential area (a populated Census block may still contain a large total share of non-residential land area). For Chicago, the data on households with no automobile is based on figures from other city’s comparable to Chicago at the time (Boston, 37%; Washington, DC, 35%; Baltimore 39%), as Chicago values were not reported. The Santiago trip distance value only includes people over 5 years old and trips over 200 meters in order to make it comparable with the trips included in the Chicago survey. The differences in trip rate and walk mode share are likely at least partly a reflection of difference in trip definition/survey methodology.

The CMA offers an additionally interesting historical reference point because Chicago in 1960 found itself at the beginning of the U.S. Federal Highways Investment program.<sup>211</sup>

<sup>209</sup> The CMA data cited in this paragraph come from NIPC, 2005 and McGuckin and Srinivasan (2003).

<sup>210</sup> The role of resource constraints, particularly the availability of water in the suburbanizing north, could also play an important role.

<sup>211</sup> Indeed, the CATS study, from which the Chicago transportation data were derived (CATS, 1959; Levinson and Wynn, 1963) marked one of the first Metropolitan transportation studies undertaken as part

Santiago, today, is in the midst of a massive highway investment scheme, primarily under the auspices of the Chilean infrastructure concession program (see, e.g., Zegras and Gakenheimer, 2000). Will the major highway investments already undertaken in Santiago (such as East-West Costanera Norte Highway completed recently and the upgrade of the North-South Panamerican Highway, both traversing the city center) and under planning stages (such as the Northeast Santiago Access) accelerate and intensify lower-density suburbanization? In the six-county Chicago Metropolitan Area,<sup>212</sup> roughly 70% of the 6.2 million people lived within a 20 kilometer radius of the downtown in 1960; through intensive suburbanization of housing and jobs, this share would decline to just 42% (of 8 million people) in 2000 (NIPC, 2005). In contrast, in 2001, roughly 90% of the Santiago Metropolitan Region's 6 million persons lived within a 20 kilometer radius of downtown.<sup>213</sup> Will Santiago, which over the period 1991 to 2001 expanded outward at double the rate of population growth, follow in Chicago's footsteps?

Again, the answer to this question will depend on numerous factors. In a purely physical sense, unlike the Chicago area, the Santiago Metropolitan Region faces considerable topographical barriers to unfettered urban expansion. Of the region's 1.5 million hectares, roughly two-thirds would be difficult (at the least) to inhabit due to topography alone (see Figure X-1).<sup>214</sup> For the remaining land – an important share of which remains fertile agricultural land – the age-old trade-off between agricultural production/open space protection and residential (and non-residential) development demands will likely persist. Whether the U.S.-style preferences (for housing, travel, etc.), exist or will exist in Santiago remains unclear. For example, in 1967, Kain (1967) estimated an equation to predict net residential dwelling unit density and demand for single family homes, based on average household auto ownership levels, income, family size and labor force participation, using municipality-level measures from the Boston Metropolitan Area. Estimating the same equation for Greater Santiago (at the *comuna* level) yields insignificant results.<sup>215</sup> Estimated at the TAZ level for Santiago, however, Kain's equations do return significant values for the independent variables. Interestingly, the models show income to have a positive and significant effect on dwelling unit density and a negative and significant effect on share of single family dwelling units. In other words, all else equal, with increased income households prefer to live in apartments and, thus, at higher dwelling unit densities.<sup>216</sup> This result may seem counter-intuitive,

---

of the U.S. Federal Highways investment planning program. Note, also, that by 1952, public authorities had taken over full operation of Chicago's public transportation services (bus and rail).

<sup>212</sup> The formal planning region for Greater Chicago (the Northeastern Illinois Planning Commission).

<sup>213</sup> In other words, Chicago already was more dispersed than Santiago today, result of both higher motorization rates and its extensive suburban rail system.

<sup>214</sup> This two-thirds figure comes from a rough estimate based on topographical elements (derived from USGS, 2005).

<sup>215</sup> The model estimated, for 34 *comunas* of Greater Santiago, was (following Kain, 1967): net dwelling unit density = function (average household income, average household employment participation, average family size, household auto ownership). None of the variables were significant at greater than 5%.

<sup>216</sup> Note, however, that in both cases, the ordinary least squares equations return r-squared values of 0.12 (dwelling unit density) and 0.19 (percentage single family dwelling unit). In each case, all variables were significant at greater than 95% (N=682; two observations were removed as dwelling unit density outliers; with these observations included, the r-squared value for dwelling unit density goes to 0.08. Unfortunately,

however, not entirely so in the context of Santiago's current development. In particular, the last 15 years have witnessed large-scale densification (the "park city"; see Chapter VII) in the first-tier suburbs, particularly in the "cone of wealth," with old suburban estate lots being consolidated and homes replaced by high-rise apartments (see Figure X-2). Some degree of status plays a role here, as middle and upper-middle income households gravitate towards neighborhoods with cache; the role of perceived public safety (apartments offering guarded entrances) also cannot be ignored.

In short, Santiago continues growing both "up" (in the form of the "park city" and the "renovated city" apartment phenomena) and "out" (in the extended "front yard" city and "marginal city" forms) (see Figure X-2). Note, while the "front yard" city tends to be associated with up-scale suburban subdivisions, the basic urban design principles implied in these residential development patterns (privatized open space, single family homes, single use zoning) can be found across the city, in developments catering to virtually all income groups (Figure X-2). These patterns of development suggest that the philosophical planning tensions – the compact traditional, continental European style development versus the Anglo-Saxon "garden city"<sup>217</sup> movement (see Chapter VII, Section VII.1.1; also Sabatini and Soler, 1995) – remain fully alive in today's Santiago.

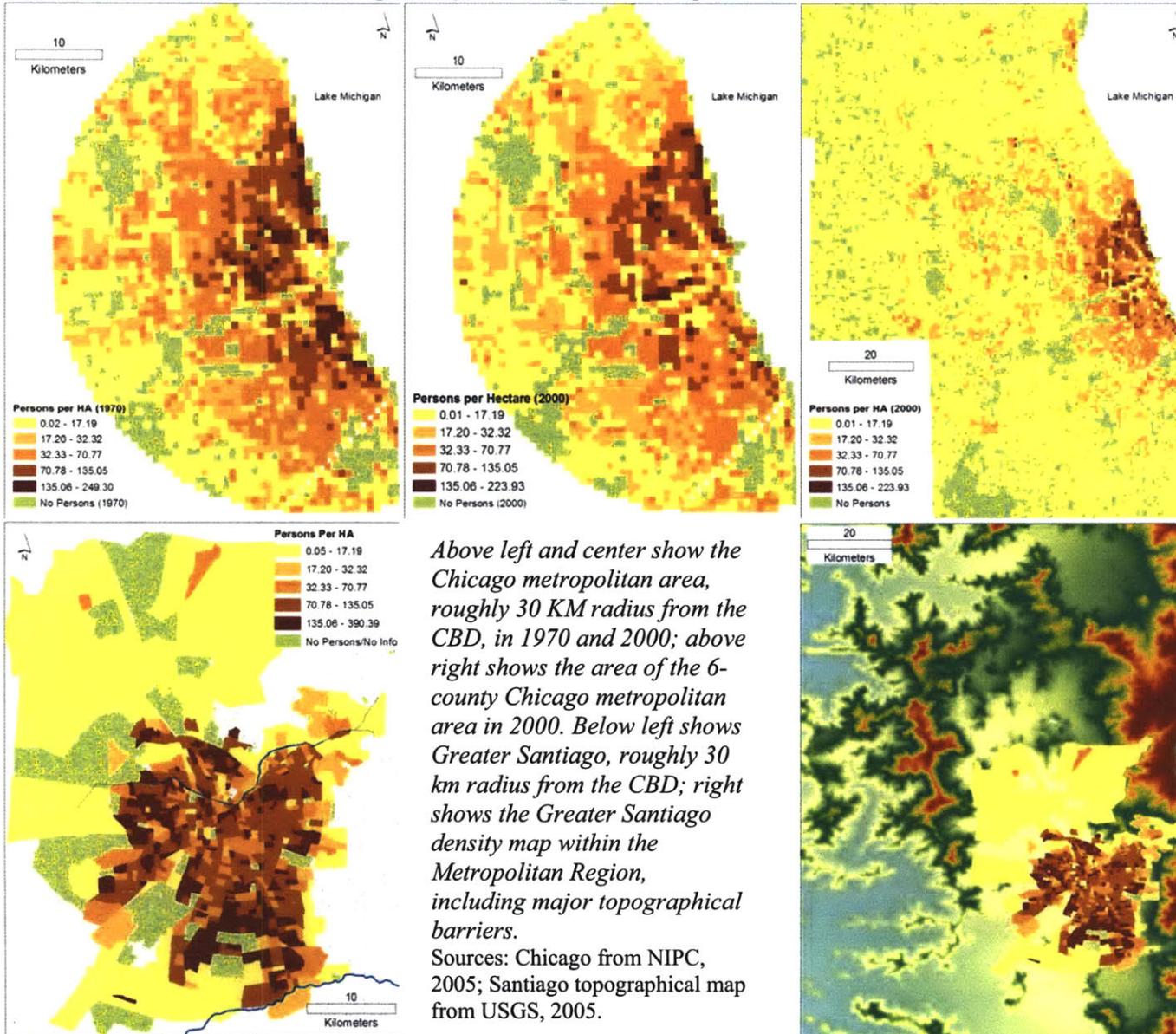
Which residential pattern will predominate in the future growth of Santiago? The answer, logically, depends on income levels (particularly in the case of future growth in the "marginal city"), governmental policies (e.g., regarding urban renovation subsidies) and regulations, consumer tastes (e.g., for continued "park city"-style apartment living versus single family home-style suburban living), and resource constraints and protections (including groundwater availability). What guidance does the research in this dissertation offer in the search for better management of growth?

---

zones from the 4 outlying *comunas* (including the the rapidly suburbanizing North) were not included due to no available built environment information.

<sup>217</sup> At the risk of confusing the reader, I adhere to Matas and Balbontin's (1987) typology of urban forms in Santiago; they use the "park city" to refer to the type of development seen in the high-rise apartments in Figure X-2 (top left) and the "front yard" city to refer to the type of development most closely linked to the "garden city" movement, i.e., Figure X-2 (right). More details can be found in Chapter VII.

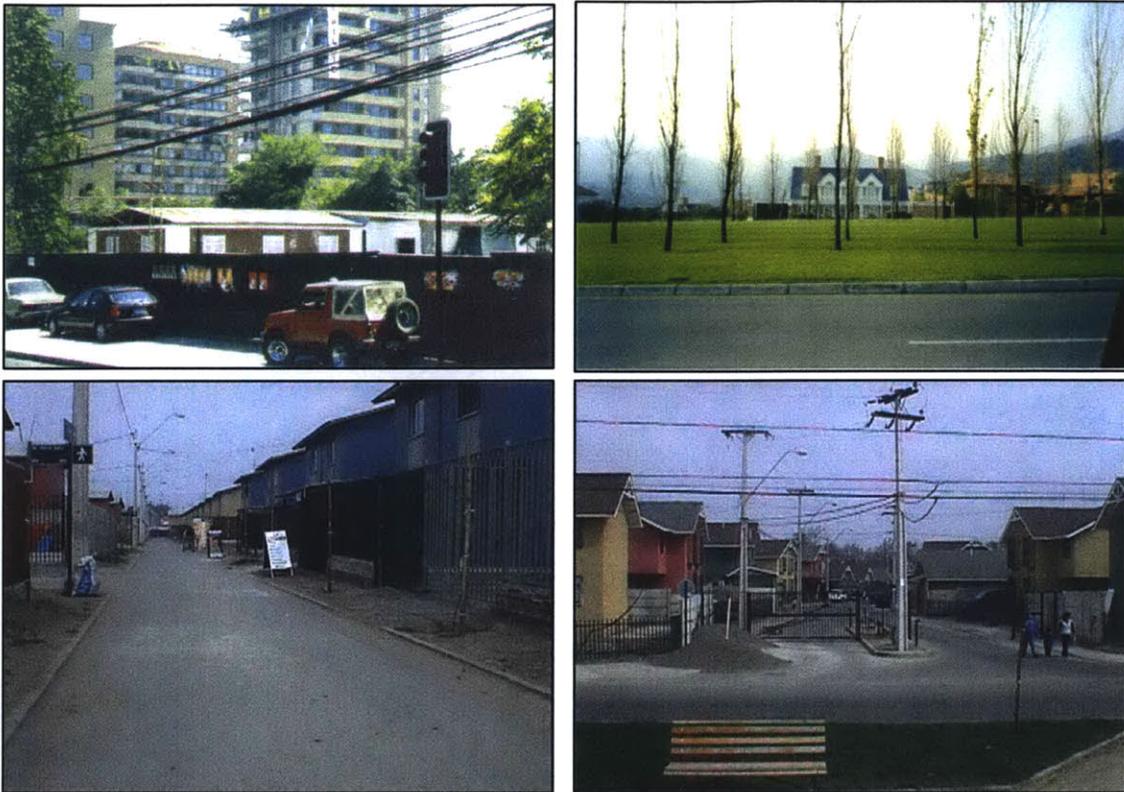
**Figure X-1. Chicago and Santiago: City and Regional Comparison**



*Above left and center show the Chicago metropolitan area, roughly 30 KM radius from the CBD, in 1970 and 2000; above right shows the area of the 6-county Chicago metropolitan area in 2000. Below left shows Greater Santiago, roughly 30 km radius from the CBD; right shows the Greater Santiago density map within the Metropolitan Region, including major topographical barriers.*

Sources: Chicago from NIPC, 2005; Santiago topographical map from USGS, 2005.

**Figure X-2. Santiago’s “Park” City, “Front Yard” Cities, and “Marginal” City**



Note: Photo on the top left shows “park city” conversion in the *comuna* of Las Condes; top right exemplifies the “front yard” city, in Lo Barnechea; bottom right is the “front yard” city in San Bernardo; bottom left represents the “marginal city” in La Pintana. Photos by the author.

### **X.3.2 Primary Implications from Modeling**

In terms of motor vehicle ownership, the modeling undertaken in Chapter IX confirmed our basic expectation for a rapidly growing economy: household income exerts the overwhelming influence when it comes to the decision to own at least one vehicle. Moving up the ownership chain (i.e., to two or three or more vehicles), however, the influence of both meso (distance to CBD) and micro-scale effects (land use mix, dwelling unit density, and apartment living) play a role, as do relative bus/auto levels of service. In terms of transportation analysis, the lesson is clear: *future transportation forecasting efforts should include built environment and transportation levels of service* for projecting household auto ownership. If not, biased forecasts are likely. For the purposes of urban planning and design, the finding also suggests that the “garden city” and the “renovated city,” as well as, more general efforts to slow urban expansion, may help reduce auto ownership.

In terms of motor vehicle use (total household vehicle distances traveled on the day of the survey), the number of household vehicles exerts the most important influence. Interestingly, meso-level built environment factors, in the form of household distance to CBD and household proximity to Metro stations have a larger influence on vehicle use than household income. In the case of the CBD influence, this evidence lends support to

“compact city” concepts. In the case of household distance to Metro stations, the evidence suggests that, on average, the Metro may induce up to 3.5 fewer vehicle kilometers per day for auto-owning households living within 1 kilometer of a Metro station. As the Metro infrastructure already exists and large areas of relatively sparsely populated land exists near an important number of Metro Stations (see Chapter VIII, e.g., Figure VIII-5), this result should provide more concrete support for transit-oriented development, including along areas of current Metro expansion. As for micro-scale urban design effects, a more gridded street network (proxied by 4-way intersections per km) apparently diminishes household motor vehicle use (with a degree of influence roughly comparable to household income).

Finally, the modeling process towards deriving accessibility metrics also revealed relevant results. For mode choice, no local built environment effects were detected for recreation trips, although for visit trips, dwelling unit density and local land use mix do influence public transportation (bus and Metro) and walk mode choice. The mode choice modeling results have two interesting implications: mode choice models may well need to vary according to trip purpose for more accurate forecasting and, for at least some of the trip types, not including local built environment variables will provide less than best models. Another interesting result from the nested destination-mode choice was the implied decision structure for *Santiaguinos*. At least when it comes to leisure trips, the typical *Santiaguino* seems to view all of the places that s/he can go by a particular mode, such as auto or bike, as more similar than the different potential leisure trip destinations. This result differs from similar types of models estimated for shopping trips in Washington, DC (Ben-Akiva and Lerman, 1985) and “other” trip tours for San Francisco (Cambridge Systematics, 2002a) and merits further exploration (particularly in the context of travel forecasting).

### **X.3.3 Accessibility and Sustainable Mobility**

The accessibility measures derived from the nested destination-mode choice models revealed, for leisure travel (recreation and visit trips) a fairly strong CBD-orientation of high accessibility zones in the city. The results also suggest, not surprisingly, severe inequalities in accessibility across income groups, with both high and medium income individuals enjoying – in virtually any part of the city – the same or higher accessibility levels than lower income households even if the latter were to locate in their most accessible locations. As we might expect, the income disparities in Santiago manifest themselves in terms of accessibility. Analysis showed the reduced accessibility the average individual would face with loss of the automobile; reductions considerably larger in size and spatial scale than due to loss of the bicycle or Metro option. This analysis also revealed, however, areas of *relative automobile independence* – areas of the city that would suffer *relatively* less if, for leisure travel anyway, if the auto option was no longer available. Interestingly, the areas were not exclusively CBD-oriented; in fact three different basic types of relatively auto-independent locations were identified: (1) outdoor amenity-oriented, urban edge locations; (2) dense residential suburban developments, characterized by small blocks on gridiron patterned streets; and (3) major urban sub-centers, including long-consolidated areas of early urban expansion of the traditional CBD and a newer southern suburban “crossroads” area.

Finally, the proposed sustainable mobility trade-off space was operationalized for the sub-set of leisure trips (recreation and visits). For the different trip purposes, spatial variations in the sustainable mobility ratio were evident, with both micro- and meso-level built environment characteristics playing a role. Looking at the 40% of the city with the “most sustainable” mobility showed a strong CBD-proximity (i.e., meso-scale) effect, although evidence also suggested a role of local built environment factors as well, such as block morphology, commercial and service land uses, and road network configuration, among other factors. Nonetheless, the results should be viewed as preliminary, in no small part because of weak explanatory power of the weighted PKT (i.e., “mobility throughput”) metric. Furthermore, as the analysis only focused on a sub-set of trip purposes, more broad analyses, including all trip purposes, would be necessary before firm conclusions regarding sustainable mobility and the role of the built environment can be made. This research has provided an important first step.

### **X.3.4 Policy Relevance of the Analytical Results**

Can the tentative nature of the conclusions lend themselves to urban planning and management recommendations in the face of Santiago’s current growth patterns? The short answer to that question is “possibly.” Perhaps the most important practical evidence comes from the various models estimated on the path to deriving the sustainable mobility metric for leisure trips in Santiago. Those models lend support for the idea of containing urban outgrowth; furthermore they show that micro-scale built environment factors do apparently influence automobile ownership and automobile use (as well as broader metrics of mobility throughput). Such results could and should be further refined and incorporated into forecasting and planning activities. More broadly, the accessibility metric has provided a first order indication of the most accessible parts of the city as well as those places that reveal a degree of automobile “independence.” These places should be more closely examined in order to discern the relevant characteristics. In turn, these characteristics could be turned into lessons for guiding new developments.

In the end, we know that Santiago will grow outward; the research here has shown, however, that controlling that rate of growth and its form will likely reduce travel demand. The results, while somewhat plainly intuitive, can still be helpful in, for example, simply lending support to existing planning efforts. For example, the ongoing efforts at urban renewal through the use of urban renovation subsidies (e.g., the “renovated city”) is clearly in line with more sustainable mobility, as would be the proposed plans for redeveloping the large de-industrializing swaths of the old industrial districts. At the same time, the growing use of transportation impact fees and environmental exactions in the suburbanizing North also seem to be supported by the research results here to the extent that they slow the pace of urban expansion or, at least, put in place incentives for creating alternative development patterns. In this regard, the government’s new regulatory scheme for managing large scale developments in this area<sup>218</sup> – the so-called *ZODUCs* (for conditional urban development zones) – also could be informed by the analytic results presented here (particularly through further

---

<sup>218</sup> Echoing, in some ways, the U.S. experience with “New Town” planning in the 1960s and 1970s (e.g., Burby et al., 1976; see also Introduction to Chapter IV).

exploration of specific areas of apparently more sustainable mobility patterns). The *ZODUCs* will ostensibly create a poly-nucleated city form, which this research indicates would be effective from a sustainable mobility perspective. Authorities would do well to try to learn from the decades of experiences in the U.S. (and other industrialized countries) in attempting to realize desired urban forms in the face of rapid suburbanization. For example, does Santiago want to look like 1990 (or 2000) Chicago in 30 years time? Scenario planning techniques (e.g., Zegras et al, 2004) offer an interesting possible means for exploring such questions.

As in most other cities around the world, authorities in Santiago, in developing and attempting to implement plans, ultimately face difficult implementation challenges. In no small part these challenges arise from the multiple government layers (across both jurisdictional and areas of responsibility); the lack of clear transportation/land use planning hierarchy and clear lines of authority/accountability; lack of any clear, coherent, and integrated relevant policy. The issues of relevant authority will likely increase in complexity as the city expands outward, further “metropolitanizing” and incorporating new jurisdictions, with their own interests, etc.

Furthermore, there are signs of increasing institutional competition in this realm, particularly the apparent emergence of two different “camps”: the infrastructuralists, heavy into road and Metro construction, and the traditional demand-/system-management types. For the moment anyway, the former seem to be in increasing control. Finally, we cannot ignore the roles of private sector actors and individual behavior; does the idea of sustainable mobility simply go against more fundamental consumer desires/lifestyle choices related to housing preferences, auto ownership? Will motorization force automobility by increasing space demands and changing urban fabric?

In terms of promoting sustainable mobility, authorities could take an important first step by using the accessibility-mobility trade-off space as proposed here. Or, at a minimum, begin formally using accessibility as a benefit indicator. Authorities already have the analytical tools to do so (i.e., *ESTRAUS* and *MUSSA*).

### **X.3.5 In Summary: Strengths, Shortcomings and Future Research**

#### *X.3.5.1 Theoretical Framework and Definitions*

The proposed operational definition of sustainable mobility provides a simple and straightforward, albeit not necessarily obvious, way of conceptualizing sustainable mobility. The framework, which builds primarily from existing terminology (e.g., accessibility) and analytical tools (e.g., discrete choice models) should be intelligible to transportation and land use planners and fully derivable with the “tools of the trade.” With a little work, the theoretical framework and metric should also be translatable to a broader audience of policy-makers and the general public. Indeed, policy-makers and the broader public should be involved in the ultimate derivation of the throughput component; the various pieces of the weighted throughput measure, which should reflect local concerns, priorities and, e.g., discount rates. Finally, as I show in the empirical case, the framework is operational, albeit imperfectly in this specific case.

### *X.3.5.2 Limitations*

The approach does not, however, come without shortcomings. In somewhat practical terms, analyses of this sort in a rapidly developing city, such as Santiago, must confront situations in flux – rapid motorization, potential instability of paths of change, possibilities for introduction of new technologies, etc. – which implies likely data/information shortfalls as well as, ultimately, forecasting challenges. Beyond this, comes the inherent complexity of the sustainability concept itself. To demonstrate the feasibility of the proposed framework, I impose somewhat artificial boundaries in the application to metropolitan-area passenger mobility. Local transport systems form part of regional transport systems which form part of national transport systems, which in turn, form part of international transport systems. Bounding the analysis to consider “only” metropolitan passenger transport forces ignorance of the broader system interactions (such as people substituting local transport with long-distance transport). Furthermore, focusing on passenger transport ignores a non-insignificant piece of the mobility sub-system, freight. The relevance of freight comes not only from its linchpin sustainability role – the movement of goods being fundamental to economic development and freight vehicles accounting for a non-trivial share of, e.g., air and noise pollutants and road damage. Freight’s importance also comes from the freight-passenger interactions, they generally share the same infrastructure and, furthermore, can in some cases be viewed as substitutes (for example, by traveling to the store, you bring freight to your house; by having home delivery of goods, freight delivery comes to you).

The transportation and, more generally, urban systems, in turn, form just part of the larger economic system, allowing for the free trade of goods, the development of comparative advantage, the increasingly seamless flow of passengers and goods to places far and wide, and consumer patterns such as enjoying tropical fruits in the darkest winter months. Some suggest, perhaps quite rightly, that many of these patterns are unsustainable on a global scale. The analysis undertaken in this dissertation has, essentially, steered clear of examining these inter-relations. Nonetheless, by being embedded in basic microeconomic behavioral theory, the analytic approach employed could potentially be linked to broader analyses. This could be an interesting area for future research.

More philosophically, questions can be raised about the analytical techniques employed, such as the utility-derived accessibility measure. The shortcomings do not come from the random utility models, per se, but rather the broader behavioral modeling approaches within which random utility models form just one type. Basically, mathematical models can only account for “what gets put in” and the underlying relationships (i.e., functional forms) assumed. We do not know if different information would produce different results. The random utility class of models operate on the basic premise that “more” is better than “less” and that individuals thereby derive satisfaction from “more” (utility), which drives choice. But, important assumptions, which actually represent a form of subjectivity, are embedded in this outwardly objective analytic technique. These assumptions (such as distribution of the error terms) will impact the results in ways in which we do not necessarily even know (for more discussion in this vein, see Smith, 1998). This discussion does not intend to debunk the analysis undertaken, but only to point out its ultimate subjectivity, even when cloaked in “objective” formulations.

### X.3.5.3 Future Research

Finally, I end this dissertation with an outline of several promising ways for extending the research. Valuable future contributions could be made in the following areas:

- Examining additional trip types, such as shopping trips. Incorporating such trips within the current framework would likely offer valuable insights.
- Improving the representation of the “value” of the destination, and the benefits derived. For example, the visit trips model did not explicit account for the specific value of the potential destination (e.g., where friends or relatives actually live).
- Incorporating household “self-selection” and the role of attitudes into the analysis. This could be done via econometric techniques (self-selection), but, more robustly, would require panel data (to get same household “before”/“after” behaviors) and, new survey instruments that specifically gauge the role of attitudes in travel behavior.
- Further developing and refining the concept of relative automobile independence. In particular, it would be useful to explore in more detail the areas which seem to perform well on this indicator and, further, see how the performance is affected with the inclusion of more trip purposes in the accessibility metric.
- Exploring alternative spatial aggregations, including effects of the modifiable areal unit problem (MAUP). It would be useful to look at alternatives to the TAZ, to gauge effects on the results. In particular, it would be useful to take a “neighborhood-oriented” approach (i.e., further attempting to identify discernible physical neighborhood forms) and/or look at other forms of spatial aggregation that might be more suited for capturing built environment effects. Moving away from the TAZ, however, faces the challenge of compatibility with formal forecasting efforts.
- Integrating the approach into existing planning tools (i.e., integrated land use transportation modeling). The framework developed here is, intentionally, fully compatible with current forecasting tools in use in Santiago (although non-trivial work would be required to enable those tools to look at all trip types on all days). This could, in theory, allow for “complete” accessibility metrics (all trips) to be derived and more accurate throughput metrics to be measured in space.
- Refining the throughput metric. Ideally, the throughput metric (i.e., weighted PKT) should be specified based on local concerns, needs, discount rates, etc. This should be developed in a transparent, participatory process and might explore alternative throughput approaches (e.g., “ecological footprint” versus “full cost” monetization of effects) and look at various potential paths of technological evolution.
- Using scenario planning techniques. Related to the previous point, it would be useful to use the sustainable mobility framework to embark on a broader-scale, participatory scenario planning exercise (e.g., Zegras, Sussman and Conklin, 2004) that would include full consideration of the broad sustainable mobility impacts and variations in weighted PKT, and, for example, gauge the possible contribution of technological improvements. Here the idea of exploring future growth patterns based on other cities’ historical trajectories could be interesting.
- Including freight in the analysis.
- Applying the approach to other metropolitan areas, in Latin America and elsewhere. In this case, the lack of quality data might pose a challenge. But, ultimately, more lessons could likely be learned by looking at a range of cities, across regions.

## A. Appendix

### A.1 Factor Analysis

Factor analysis refers to a family of statistical (in some cases, strictly speaking, mathematical) techniques that aim to uncover the latent structure (e.g., dimensions, factors) of a large set of variables. Essentially a means of data reduction, factor analysis enables the researcher to distinguish particular patterns and identify coherence among many different variables. Basically, factor analysis examines the correlations among different (manifest) variables, identifying those variables which are relatively homogenous (or correlated), and grouping those variables into different (latent) factors.

Technically, the term factor analysis encompasses several different approaches, which differ in both purpose and statistical technique. The most basic approach, exploratory factor analysis (EFA), operates under the assumption of no *a priori* structure underlying the data; in this case, factor analysis is used to explore and summarize the underlying data. Confirmatory factor analysis (CFA), on the other hand, begins with a hypothesis on factor structure (e.g., number and meaning of factors) and aims to determine whether the underlying variables are related, as predicted, on the pre-supposed factor structure. Confirmatory factor analysis belongs to the latent variable modeling technique known as structural equation modeling (see e.g., Everitt and Dunn, 2001).

Several different factoring methods can be used in exploratory factor analysis. Principal components analysis (PCA) uses the correlation or covariance matrix to determine the common *and* unique variance of the variables. Basically, PCA seeks a linear combination of variables to maximize the variance; this variance is “extracted” into the first component; the next component provides a linear combination of the variables which explains the greatest amount of the remaining variance, *subject to not being correlated to the first component*. All remaining components are subsequently derived, analyzing total (common and unique) variance and producing components that are uncorrelated (orthogonal). As opposed to PCA, principal factor analysis (PFA) (also called principal axis factoring or common factor analysis) aims to derive the least number of factors which represent the *common* variance of the variables, *excluding the unique variance*. In practice, PCA and PFA will often produce similar results; this will be the case when the specific variances are small. Factor analysis techniques enable the potential to assess a large number of variables in “collapsed form;” while not a substitution for theory, factor analysis can provide an first step towards the elaboration of theory (Robson, 1969).

### A.2 Factor Analysis and Cities: Ecological Origins

Factor analysis finds its origins in psychology at the beginning of the 20<sup>th</sup> Century and continues to be used widely in the behavioral sciences,<sup>219</sup> biological sciences, physical sciences (e.g., meteorology), finance, etc. Urban studies-related applications of factor analysis date back to the late 1930s, when applications appeared in the growing field of

---

<sup>219</sup> “During the last forty years factor analysis has become one of the most used methodical approaches within psychology, and hundreds of psychological tests have been developed based on factor analysis” (Kubinger, 2003).

urban sociology and human ecology, as pioneered by those of the “Chicago School.”<sup>220</sup> In 1936, Gosnell and Schmidt (1936) studied variables – including home ownership rates, rental levels, and immigration – influencing voter behavior in Chicago. In 1942, Price (1942) published a journal article, which by his knowledge, constituted the first use of “complete multiple factor analysis” applied to the characteristics of cities; his analysis looked at 15 variables (primarily demographic and economic) in 93 US cities which he concluded could be characterized along four dimensions – size, function, standard of living, and economic activity. In 1955, Bell (1955) uses factor analysis to test a proposed social typology (Shevky’s “social area analysis”) of urban sub-populations originally derived from 1940 census tract data for Los Angeles county: economic status, family status, and ethnic status. Van Ardsol et al (1958), using census tract data from 10 U.S. cities, determine that the “Shevky system” (sometimes referred to as the “Shevky-Bell typology”) is basically generalizable to those cities as well.

The application of factor analysis in urban social ecology to explain sources of spatial differentiation between and within cities became known as “factorial ecology.”<sup>221</sup> Rees (1971) reports on more than 40 relevant studies of intra-urban level analyses carried out over the period 1957-1971 for 45 different cities in the U.S., Canada, the UK, Australia, India, Scandinavia and Egypt. In 1971, the journal *Economic Geography* published a special supplement on the use of “factorial ecology” for understanding and comparing urban areas (*Economic Geography*, 1971). Most of these again look essentially at the original “Shevky system,” reporting on variations in statistical techniques, theoretical and practical problems and challenges, and applications in a variety of developed and developing country settings. Robson (1969) builds on the existing research base at the time and further elaborates in a direction relevant to identifying “meaningful social areas” in an urban setting within which “structural relations might be tested.” In his application to Sunderland, a small city in the UK, Robson uses principal components analysis to provide “objective parameters” which suggest “regional patterning.” In his analysis, he included 30 variables (including two variables explicitly measuring residential physical characteristics) measured for 263 enumeration districts, derived five principal components and calculated component scores for areal units. He then uses the scores of the first two components (accounting for 60% of the variation) in cross-classification to identify 14 different (of 16 potential) combinations of components present in Sunderland. He then uses the extreme scores on the third and fourth components to further subdivide relevant sub-ares. Robson then uses this regional patterning to provide a “sampling framework” for the selection of areas to evaluate the spatial variation in the attitudes to education.

All of these studies look at socio-economic and demographic variables and resultant dimensions, with an aim towards better understanding the patterns of residential differentiation within urban areas. Note, however, the overwhelming sociological underpinning of the analyses: urban spatial form was defined according to, essentially,

---

<sup>220</sup> Robson (1969) offers a good brief overview of the emergence of the concept/term “human ecology” within the early 20<sup>th</sup> Century urban theorists/sociologists, studying at the University of Chicago and influenced by the writings of Darwin.

<sup>221</sup> Rees (1971) and Janson (1980) both credit Sweetser (1964) with coining this term.

societal structure. According to Wyly (1999), factorial ecology reached its “high water mark” in the 1960s and by the early 1970s factorial ecology faced something of a “backlash” and somewhat fell out of favor among relevant academic disciplines, as quantitative descriptions of urban structure were replaced by quantitative techniques of explaining urban dynamics (i.e., urban modeling) or more qualitative theories of class formation and class conflict and globalization and world cities (e.g., Marxist theories and “World city” theories).<sup>222</sup> Nonetheless, use of the techniques in urban sociological and geographical research continued in the 1980s and 1990s, including in the development of socio-economic and demographic data-based “urban deprivation” indexes (see Kitchen (2001) for a brief review and example application). Seeing a need to return to quantitative evaluations of residential differentiation, Wyly (1999) applies factor analysis to 1980 and 1990 census tract data for the Minneapolis, MN metropolitan area in order to gauge the extent to which urban demographic trends have altered the “ecology of the American city.” His analysis leads him to conclude that patterns of residential structure display a remarkable stability (when compared with the first wave of post-World War II factorial ecology analyses), particularly for the white middle class.

### **A.3 Recent Applications and Direct Precedents**

By at least the end of the 1980s, factor analytic techniques find their way into work attempting to measure the characteristics of the *built* (as opposed to sociological) urban environment, with a particular eye towards transportation effects (e.g., Cervero, 1989). The appearance of the technique in such applications seems natural; after all, many different variables can be used to measure aspects of the built environment. The multiplicity of variables, plus the fact that many of them will often be highly correlated (for example, high residential density may be highly correlated with the spatial mix of commercial areas) suggests that factor analysis and the resultant latent variables (factors) may provide a useful technique to simplify the multiple means of measuring built space *and* allow for the identification of several understandable dimensions along which the spatial character of a city can be differentiated.

The many recent examples from the relevant literature can be divided into two basic types of uses: data reduction and classification. Data reduction approaches basically use factor analysis techniques to derive a reduced number of variables that can be used in further analysis to deal with, for example, issues of multi-collinearity. For example, Cambridge Systematics (1994) analyzed 24 built environment variables, using PCA to derive five components representing different land use/urban design variables which were then used in simple statistical analyses (e.g., difference of means tests) to assess influences on, e.g., mode shares. Sermons and Koppelman (1998) follow the factorial ecology approach, deriving family status and socioeconomic status factors (at the census tract level) for inclusion in a residential choice model. Cervero and Kockelman (1997), in their study of San Francisco Bay Area neighborhoods, collected data on 22 variables representing the 3Ds of the built environment and used factor analysis to extract two factors, drawing from 12 of the built environment variables that represented density (land use intensity) and design (walking quality). Again, these factors were then used as

---

<sup>222</sup> Notice how these developments match the modernist/post-modernist urban planning and design evolution discussed in Chapter II.

variables in travel behavior models. Srinivasan (2001, 2002) also uses factor analysis, in this case to derive variables representing residential location types drawing from many measures that describe the land use, transportation network, and accessibility characteristics of locations in a city (e.g., grid-like street patterns, mixed-use commercial and residential development, a mix of different housing densities, and variations in accessibility levels). Using data from the Seattle, Washington Metropolitan Area, Krizek (2003b) calculates – at the 150-meter grid cell – housing unit and person density, the number of employees in neighborhood retail services, and street design, averages these values across neighboring cells, and reduces these three measures into a single dimension, using factor analysis to extract a single factor that accounted for 79% of the variation in the three variables.<sup>223</sup> The factor scores for each grid cell then is used as the neighborhood accessibility index for that cell.

In terms of classification approaches, in his late 1980s study of the effects of suburban employment centers (SECs) on mobility, Cervero (1989) utilized factor analysis on 14 land use variables<sup>224</sup> that represented density, size, design and land uses. Cervero's ultimate aim was to develop a method for classifying SEC types, from among pre-defined SECs.<sup>225</sup> He derived four factors via factor analysis (first uses PCA, then PAF) with orthogonal (Varimax) rotation (he justifies the orthogonality by reporting low correlation – the highest being 0.2 – among the subsequent factors), which directly mapped to his variable categorization of density, size, design and land use. These four factors accounted for 88 percent of the variation in the original variables. Cervero goes on to use the factor scores in a cluster analysis in order to group the 50 SEC cases into different typologies.<sup>226</sup>

More recently, Bagley et al (2002) also use factor analysis to assess neighborhood characteristics (actually residential type), using data from household interviews (852 individuals from different households) and from site surveys (15 variables come from the household interviews and 3 come from site surveys, which the authors label as disaggregate and aggregate, respectively). Variables included speed limits of road, grid-like street configuration, population density, distance to stores, public transit convenience, etc. Ten of the variables were collected in binary form (e.g., even population density is coded as simply “high” or “low”), which poses some doubts as to the applicability of traditional factor analytic techniques.<sup>227</sup> While Bagley et al had a priori factor structures (i.e., a “traditionalness” construct), they did not perform

---

<sup>223</sup> He used principal components (and varimax rotation) on the *logarithmically transformed* variables to derive a single component that accounted for nearly 80% of the variation in the three variables (pp. 281-282; p. 285).

<sup>224</sup> Cervero included size of workforce and employees per acre in his land use variables.

<sup>225</sup> See Cervero (pp. 18-19) for a description of how the SECs were defined, chosen and bounded.

<sup>226</sup> Seven additional SEC cases were, that Cervero called “large office corridors” were left out of the factor and cluster analysis as Cervero suggests they would have disproportionately influenced the analysis due to their size and scale.

<sup>227</sup> There is not unanimity in the literature on the appropriateness of using binary (dichotomous) data in factor analytic techniques, e.g.: “Ordinal and dichotomous variables have been submitted to a factor analysis in the social and behavioral sciences. Unless the distributions of the variables are strongly nonnormal, factor analysis seems to be robust to minor violations of these assumptions.” (University of Texas at Austin Statistical Services, 1995); “the use of dichotomous variables is problematic. As a matter of fact, factor analysis applied to dichotomous variables leads to artificial results.” (K. Kubinger, 2003).

confirmatory factor analysis, but instead tried both principal component and principal axis factoring techniques (both, technically, exploratory factor analysis methods), applying different rotations. They report having obtained consistent results from the different combination of methods and present the results from principal components with oblique rotation. According to their results, two distinct dimensions emerged from the analysis: a traditional factor (with variables related to population density and public transit convenience loading positively, and variables related to home size, presence of a backyard, and parking availability loading negatively) and a suburban factor (with variables related to speed limit, distance to nearest grocery store and park, and ease of cycling loading positively, and grid street network loading negatively). Their findings led them to conclude that “traditionalness” is not a single “either-or” characteristic; instead, neighborhoods can score high or low on both characteristics.

#### **A.4 Controversies**

Despite a number of precedents, factor analysis remains a somewhat controversial analytical technique. As can be judged from the brief reviews above, there is considerable variation in the different techniques used. In rigor, many of the studies should have apparently used confirmatory factor analysis techniques (e.g., both Cervero and Kockelman (1997) and Bagley et al (2002) had a priori expectations of the dimensions). Those that derive factor scores rarely make it clear which technique for deriving factor scores they employ. Unfortunately, little consistency exists in relevant terminology, there is no agreement on the criteria used for, e.g., cutting off the number of factors to extract or the variables to include in interpreting factors, type of rotation to use, etc. In a recent assessment of factor analysis, Preacher and MacCallum (2003) recommend that use of PCA be avoided, oblique (not orthogonal) rotation be used, and a combination of criteria be used to determine the appropriate number of factors to be extracted. Srinivasan’s (2000) use of factor analysis provides a very thoroughly documented approach, using both exploratory and confirmatory factor analysis.

#### **A.5 The Millennium Cities Database**

With these strong cautions in mind, I attempted factor analysis techniques on the Millennium Cities Database (Kenworthy and Laube, 2001), as a means of deriving dimensions along which different cities’ transportation-related variables vary (see Chapter VI). This was actually an update of an analysis carried out earlier (Gakenheimer & Zegras, 2004). A total of 83 cities were included in the analysis; the selection of these cities represented a balance between variables available and geographic coverage. As can be seen from Table A-1, Western European cities are heavily represented, followed by North American and developing Asian. A total of 24 variables was included in the analysis; variable selection was based on avoiding repetitious variables<sup>228</sup> and the variable’s individual Measure of Sampling Adequacy (MSA) (only variables with  $MSA > 0.5$  were included). Overall, the Kaiser-Meyer-Okin MSA for all included variables was 0.798.<sup>229</sup>

---

<sup>228</sup> The MCD included over 200 variables; many of these were only subtle variations of each other.

<sup>229</sup> The Bartlett’s Test of Sphericity = 1472.5;  $p < 0.0001$ .

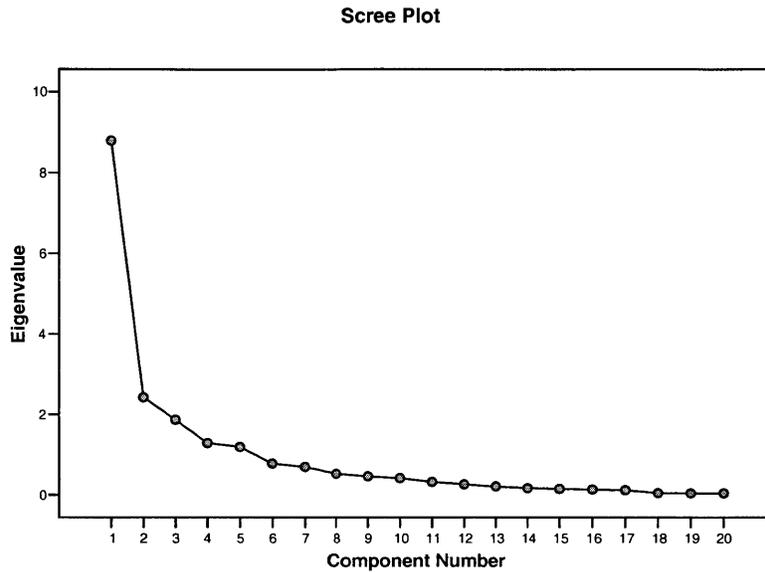
**Table A-1. Cities Analyzed from Millennium Cities Database**

Region	Number of Cities	Cities
Western Europe	32	Vienna, Zurich, Stuttgart, Stockholm, Oslo, Newcastle, Nantes, Munich, Milan, Marseille, Manchester, Madrid, Lyon, London, Paris, Rome, Ruhr, Geneva, Glasgow, Graz, Hamburg, Helsinki, Amsterdam, Athens, Barcelona, Berlin, Berne, Bologna, Brussels, Copenhagen, Frankfurt, Dusseldorf,
South America	3	Bogotá, São Paulo, Curitiba
North America	15	Atlanta, Calgary, Chicago, Denver, Houston, Los Angeles, Montreal, New York, Ottawa, Phoenix, San Diego, San Francisco, Toronto, Vancouver, Washington
Middle East	3	Tehran, Riyadh, Tel Aviv
Eastern Europe	3	Cracow, Budapest, Prague
Australia	5	Melbourne, Brisbane, Perth, Sydney, Wellington
Developing Asia	12	Shanghai, Seoul, Mumbai, Manila, Kuala Lumpur, Jakarta, Ho Chi Minh, Guangzhou, Chennai, Beijing, Bangkok, Taipei
Africa	5	Johannesburg, Harare, Cape Town, Cairo, Tunis
Developed Asia	5	Singapore, Sapporo, Osaka, Hong Kong, Tokyo

Based on the scree plot (Figure A-1) and Eigenvalues, five components were extracted; ultimately principal components extraction was employed, with Promax (oblique) normalization which allows the components to be correlated with each other. As mentioned above, principal components analysis (PCA) analyzes all the variance (both common and unique) among the variables, while principal axis factoring (PAF) analyzes only the variance in the data that is shared with other variables. Technically, PAF would be the better approach to explore the underlying factors for the theoretical purposes here (i.e., how many relevant dimensions of variation exist?). However, PAF would not produce a solution on the data as at least one variable's communality exceeded one, suggesting that the model is not appropriate for this data set.<sup>230</sup> As such, I ended up using PCA, but recommend that these results be viewed with caution. Table A-2 shows the variable loadings on the five extracted components and Table A-3 shows the correlation matrix among the components. Chapter VI provides an interpretation of these components.

<sup>230</sup> This is, apparently, the "Heywood case" (e.g., Gorsuch, 1983). The communalities (the diagonal elements in the variable matrix) are in the principal components case equal to one (by definition, since the principal components account for all variance); in the case of principal axis factoring, however, communality estimates must be used.

**Figure A-1. Scree Plot & Eigenvalues for the Components Extracted from the MCD**



**Table A-2. Pattern Matrix of Component Loadings for the MCD**

Variable	Component Loadings				
	1	2	3	4	5
Road/1000	0.440				
Cars/1000	0.306				-0.395
MC/1000		-0.577		0.354	0.542
VKM/Car	0.570				
Taxi/Mn Pers				1.099	
Road Speed	0.651			-0.496	
Rail VKM/HA	0.447		-0.968		
Trips/Cap					-0.465
Public Transport Mode Share		0.411	-0.316	0.541	
NMT Mode Share	-0.494	0.734			
Private Transport Mode Share	0.350	-0.551			
Avg Trip Distance	1.125				
Avg. Work Trip Distance	1.034				
Avg Time PT Trip			0.342	0.585	
Avg User Cost Car Trip		0.684	0.316		
Use Cost PT Trip		0.341		-0.462	0.909
PT Cost Recover		-0.323			1.073
% GDP on PT ops		1.051			
% GDP on private Ops		0.516	0.716		
Total private Cost Share GDP		0.516	0.744		
Total PT cost Share GDP		0.903			
Private transport Energy/Capita	0.648				
CO per Capita	0.332		0.447		
Total transport deaths per million			0.662		
<b>% of Variance Explained</b>	<b>44%</b>	<b>12%</b>	<b>9%</b>	<b>6%</b>	<b>6%</b>

**Table A-3. Component Correlation Matrix for the MCD**

Component	1	2	3	4	5
1	1.000	-0.302	0.487	-0.533	-0.363
2	-0.302	1.000	-0.018	0.492	0.489
3	0.487	-0.018	1.000	-0.242	0.044
4	-0.533	0.492	-0.242	1.000	0.550
5	-0.363	0.489	0.044	0.550	1.000

### A.6 Factor Analysis of Santiago’s Built Environment Grid Cells

As presented in Chapter VII, I also attempted a factor analysis of the 250 meter square grid cells that were constructed to represent Santiago’s built environment. The original intent was to follow, to some degree, Robson’s (1969) approach to spatial classification with the goal of defining specific neighborhoods based solely on spatial characteristics (as measured in the grid cells). One hypothesis was that grid cells of certain characteristics would naturally cluster in space; furthermore, I hypothesized that these clustered grid cells would match the neighborhood typologies identified for Santiago (see Chapter VII, Table VII-3).

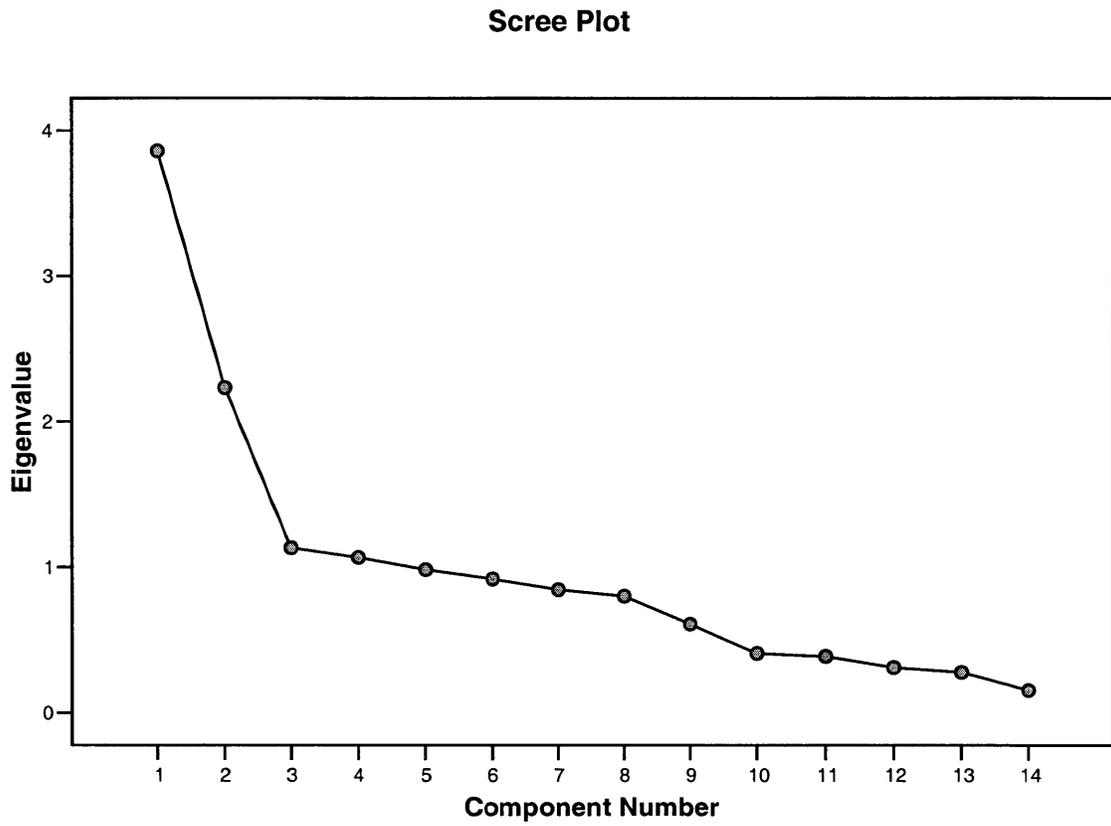
A process similar to that described above was followed to analyze the grid cells. In this case, the number of observations was 10,169 (the total number of populated grid cells covering the city; the total number of cells covering the city is 13,978). Only cells with at least 5% of the constructed area in residential use were included, since the purpose was to identify places where people lived. Similar to the MCD analysis (described above), however, factor analysis on the grid cells could only be satisfactorily completed using principal components. Despite its theoretical appeal, principal axis factoring in this case again seemed to present a “Heywood” case (see footnote 230).<sup>231</sup> Once again, principal components analysis was thus employed. Based on the scree plot and Eigenvalues (Figure A-2) four components were extracted.<sup>232</sup> Again, the variables ultimately chosen to include in the PCA were based on non-repetition of concepts and on the MSA; all variables retained in the final analysis had individual MSA values greater than 0.56; overall, the Kaiser-Meyer-Okin MSA for all included variables was 0.760.<sup>233</sup> The results from the PCA, including variable loadings and component correlation are included in Chapter VII, Table VII-4.

<sup>231</sup> Given the fact that the purpose was to confirm the neighborhood typologies, ultimately confirmatory factor analysis using structural equation modeling would be the most appropriate approach if, of course, neighborhoods could be adequately delineated, which was the purpose of the factor analysis of the grid cells.

<sup>232</sup> In this case, a case could be made, via the scree plot, for extracting just three components (the point at which the scree plot levels off); component 4 had an eigenvalue of 1.067 while component 5 had an eigenvalue of 0.984.

<sup>233</sup> The Bartlett’s Test of Sphericity = 48536;  $p < 0.0001$ .

Figure A-2. Scree Plot & Eigenvalues for the Components from the Grid Cells



## REFERENCES

- Adams, W.T. 1959. Factors Influencing Mass-Transit and Automobile Travel in Urban Areas. *Public Raods*, 30, No. 11, December, pp. 256-260.
- Aguirre A., B. and S. Castillo F. 2004. El espacio público moderno. Sueños y realidades de Karl Brunner en Santiago de Chile, 1929-1934. *Revista de Diseño Urbano y Paisaje*, Vol. 1, no. 3.
- Allen, W.B., D. Liu, S. Singer. 1993. Accessibility Measures of U.S. Metropolitan Areas. *Transportation Research B*, Vol. 27B, No. 6, December, pp. 439-449.
- Ampt, E.S. and J. de D. Ortúzar. 2004. On Best Practices in Continuous Large-scale Mobility Surveys. *Transport Reviews*, Vol. 24, No. 3, May, pp. 337-363.
- Anderson, W.P., P.S. Kanaroglou, E.J. Miller. 1996. Urban Form, Energy and the Enviornment: A Review of Issues, Evidence and Policy. *Urban Studies*, Vol. 33, No. 1, pp. 7-35.
- Arentze, T.A., H. Timmermans. 2004. Information gain, novelty-seeking, and travel: a model of dynamic activity travel behavior under conditions of uncertainty. *Transportation Research A*, vol. 39, pp. 125-145.
- Asian Development Bank (ADB). 2001. *Urban Indicators for Managing Cities*. Manila.
- Association of Bay Area Governments (ABAG). 1985. Jobs/Housing Balance for Traffic Mitigation: Interstate 680 and Interstate 580 Corridor Study. Center for Analysis and Information Services, Oakland, November.
- Badoe, D.A. and E.J. Miller. 2000. Transportation–land-use interaction: empirical findings in North America, and the implications for modeling. *Transportation Research Part D*, 5, pp. 235-263.
- Bagley, M.N. and P.L. Mokhtarian. 2002. The impact of residential neighborhood type on travel behavior: A structural equations modeling approach. *The Annals of Regional Science*, Vol. 36, pp. 279–297.
- Bagley, M.N., P.L. Mokhtarian and R. Kitamura. 2002. A Methodology for the Disaggregate, Multidimensional Measurement of Residential Neighbourhood Type. *Urban Studies*, Vol. 39, No. 4, pp. 689–704.
- Banco Central de Chile. 1999. *Anuario de Cuentas Nacionales de Chile*. Santiago, May.
- Banco Central de Chile. 2004. *Producto Interno Bruto Regional 2002-2003, Base 1996*. Last Accessed 19 May 2005 at: <http://www.bcentral.cl/esp/publ/estad/aeg/aeg07.htm>.

- Banco Central de Chile. 2005a. Índice de Precios al Consumidor IPC. Last accessed 19 May 2005 at: <http://www.bcentral.cl/esp/infoeconomica/seriesindicadores/>.
- Banco Central de Chile. 2005b. Tipo de Cambio Observado: Pesos por US\$ 1. Last accessed 19 May 2005 at: <http://www.bcentral.cl/esp/infoeconomica/seriesindicadores/>.
- Baradaran, S. and F. Ramjerdi. 2001. Performance of Accessibility Measures in Europe. *Journal of Transportation and Statistics*, September/December, pp. 31-48.
- Barrett, J. and A. Scott. 2003. The Application of the Ecological Footprint: a case of passenger transport in Merseyside. *Local Environment*, Vol. 8, No. 2, pp. 167-183.
- Bartholomew, K. undated. Making the Land Use, Transportation, Air Quality Connection (LUTRAQ) – Freeways or Communities: It's Your Choice. 1,000 Friends of Oregon, Portland. Last Accessed 22 May, 2005 at: [www.friends.org/goods/pdfs/itsyourc.pdf](http://www.friends.org/goods/pdfs/itsyourc.pdf).
- Batty, M. and S. Rana. 2002. The Automatic Definition and Generation of Axial Lines and Axial Maps. Paper 58, Centre for Advanced Spatial Analysis, University College London, September ([http://www.casa.ucl.ac.uk/working\\_papers/paper58.pdf](http://www.casa.ucl.ac.uk/working_papers/paper58.pdf)).
- Baumol, W.J. 1968. On the Social Rate of Discount. *The American Economic Review*, Vol. 58, No. 4, September, pp. 788-802.
- Beesley, M. and J. Kain. 1964. Urban Form, Car Ownership and Public Policy: an Appraisal of Traffic in Towns. *Urban Studies*, Vol. 1, No. 2, pp. 174-203.
- Beinart, J. 2004. Modern and Post-modern Urbanism. Lecture 19 from *Theory of City Form*. MIT Course 4.241J/11.330J. Spring, Lecture notes available at: [www.core.org.cn/OcwWeb/Architecture/4-241JSpring2004/LectureNotes/detail/lecture19.htm](http://www.core.org.cn/OcwWeb/Architecture/4-241JSpring2004/LectureNotes/detail/lecture19.htm)
- Bell, W. 1955. Economic, Family, and Ethnic Status: An Empirical Test. *American Sociological Review*, Vol. 20, No. 1, February, pp. 45-52.
- Bellomo, S. and E. Edgerley Jr. 1971. Ways to Reduce Air Pollution Through Planning Design and Operations. *Highway Research Record 356: Social, Economic, and Environmental Factors of Transportation*, pp. 139-157.
- Ben-Akiva. 1973. *Structure of Passenger Travel Demand Models*. PhD Dissertation, Department of Civil Engineering, MIT, Cambridge, MA.
- Ben-Akiva, M. and S. Lerman. 1979. Disaggregate Travel and Mobility-Choice Models and Measures of Accessibility. *Behavioural Travel Modelling* (D. Hensher and P. Stopher, Eds.). Proceedings of the 3<sup>rd</sup> International Conference on Behavioural Travel Modeling, Tanunda, Australia 1977. Croom Helm, London, pp. 654-679.

Ben-Akiva, M. and S. Lerman. 1985. *Discrete Choice Analysis: Theory and Applications to Travel Demand*. MIT Press, Cambridge, MA.

Bento, A.M. M. L. Cropper, A.M. Mobarak, K. Vinha. 2004. The Impact of Urban Spatial Structure on Travel Demand in the United States. Working Paper EB2004-0004. University of Colorado, Institute of Behavioral Science, Research Program on Environment and Behavior, January, Boulder (<http://www.colorado.edu/ibs/pubs/eb/eb2004-0004.pdf>).

Bhat, C., S. Handy, K. Kockelman, H. Mahmassani, Q. Chen, L. Weston. 2000. Accessibility Measures: Formulation Considerations and Current Applications. Research Report No. 7-4938-2. Conducted for the Texas Department of Transportation by the Center for Transportation Research, University of Texas at Austin, September.

Black, W.R. 1996. Sustainable Transportation: a U.S. Perspective. *Journal of Transport Geography*, Vol. 3, pp. 159-166.

Black, W.R. 2000. Toward a Measure of Transport Sustainability. Paper prepared for presentation at the 79th Annual Meeting of the Transportation Research Board, Washington, DC, 9-13 January.

Black, J., A. Paez, P. A. Suthanaya. 2002. Sustainable Urban Transportation: Performance Indicators and Some Analytical Approaches. *Journal of Urban Planning and Development*, Vol. 128, No. 4, December, pp. 184-209.

Boarnet, M. and R. Crane. 2001a. The influence of land use on travel behavior: specification and estimation strategies. *Transportation Research Part A*, 35, pp. 823-845.

Boarnet, M. and R. Crane. 2001b. *Travel by Design: The Influence of Urban Form on Travel*. Oxford University Press.

Boarnet, M. and S. Sarmiento. 1998. Can Land-use Policy Really Affect Travel Behaviour? A Study of the Link between Non-work Travel and Land-use Characteristics. *Urban Studies*, Vol. 35, No. 7, pp. 1155-1169.

Borah, W. 1980. Latin American Cities in the Eighteenth Century: A Sketch. *Urbanization in the Americas: The Background in Comparative Perspective* (W. Borah, J. Hardoy, G. Stellar, Eds.), Proceedings of Section VII, The Process of Urbanization, International Congress of Americanists, Vancouver, 11-17 Aug, 1979, published by History Division, National Museum of Man, Ottawa, Canada.

Bossel, Hartmut. 1999. Indicators for Sustainable Development: Theory, Method, Applications. A Report to the Balaton Group. Winnipeg: International Institute for Sustainable Development.

- Bourne, L.S. and G.M. Barber. 1971. Ecological Patterns of Small Urban Centers in Canada. *Economic Geography*, Vol. 47, June, pp. 258-265.
- Browne, J., E. Sanhueza, E. Silsbe, S. Winkelman, C. Zegras. 2005. *Getting on Track: Finding a Path for Transportation and the CDM*. International Institute for Sustainable Development, Winnipeg, Manitoba.
- Burby, R.J., S.F. Weiss, et al. 1976. *New Communities USA*. Lexington, MA, Lexington Books.
- Bureau of Transportation Statistics (BTS). 1997. *Transportation Statistics Annual Report – 1997*. U.S. Department of Transportation.
- California Air Resources Board (CARB). 2004. *California's Air Quality History Key Events*. Last updated March 2004, last accessed 15 May 2005 at: <http://www.arb.ca.gov/html/brochure/history.htm>.
- Cambridge Systematics. 1994. The Effects of Land Use and Travel Demand Management Strategies on Commuting Behavior: Final Report. Prepared for U.S. Department of Transportation and U.S. Environmental Protection Agency, DOT-T-95-06, November.
- Cambridge Systematics. 1997. *Vehicle Availability Modeling: Final Report Volume 1*. Prepared for the U.S. Federal Highway Administration, May.
- Cambridge Systematics. 2002a. *Destination Choice Models: Final Report*. Prepared for the San Francisco County Transportation Authority as part of the San Francisco Travel Demand Forecasting Model Development, 1 October.
- Cambridge Systematics. 2002b. *Vehicle Availability Model: Final Report*. Prepared for the San Francisco County Transportation Authority as part of the San Francisco Travel Demand Forecasting Model Development, 1 October.
- Cameron, I., J.R. Kenworthy, T.J. Lyons. 2003. Understanding and predicting private motorised mobility. *Transportation Research Part D*, vol. 8, pp. 267-283.
- Cameron, I. T.J. Lyons, J.R. Kenworthy. 2004. Trends in vehicle kilometers of travel in world cities, 1960-1990: underlying drivers and policy responses. *Transport Policy*, Vol. 11, pp. 287-298.
- Carrasco, J.A. and J. de Dios Ortúzar. 2002. Review and assessment of the nested logit model. *Transport Reviews*, Vol. 22, No. 2, pp. 197-218.
- Carroll, J.D. 1952. The Relation of Homes to Work Places and the Spatial Pattern of Cities. *Social Forces*, Vol. 30, No. 3, March, pp. 271-282.

- Castañeda, B. 1999. An Index of Sustainable Economic Welfare (ISEW) for Chile. *Ecological Economics*, Vol. 28, pp. 231–244.
- Cavric, B.I., A.C. Moshia, M. Keiner. 2004. The Case Study Cities: Santiago de Chile, Johannesburg, Gaborone. Chapter 3 in *From Understanding to Action: Sustainable Urban Development in Medium-Sized Cities in Africa and Latin America* (M. Keiner, C. Zegras, W. Schmid, D. Salmerón, Eds.), Springer, Dordrecht, The Netherlands.
- Center for Sustainable Transportation (CST). 2002. Definition and Vision of Sustainable Transportation. Mississauga, ON, October, last accessed on 8 April, 2004 at: <http://www.cstctd.org/CSTmissionstatement.htm>.
- Centro de Estudios del Desarrollo (CED). 1990. *Santiago Dos Ciudades: Análisis de la Estructura Socio-económica-espacial del Gran-Santiago*. Santiago, November.
- Cervero, R. 1989. *America's Suburban Centers: The Land Use-Transportation Link*. Unwin Hyman, Boston, 1989.
- Cervero, R. 2002. Built environments and mode choice: toward a normative framework. *Transportation Research Part D*, 7, pp. 265-284.
- Cervero, R. and R. Gorham. 1995. Commuting in Transit Versus Automobile Neighborhoods. *Journal of the American Planning Association*, Vol. 61, pp. 210-225.
- Cervero, R. and K.M. Kockelman. 1997. Travel demand and the three Ds: Density, Diversity and Design. *Transportation Research Part D: Transport and Environment*, Vol. 2, pp. 199-219.
- Cervero, R. and C. Radisch. 1996. Pedestrian versus automobile oriented neighborhoods. *Transport Policy*, Vol 3, No. 3, pp. 127-141.
- Chaskin, R.J. 1995. *Defining Neighborhood: History, Theory, and Practice*. The Chapin Hall Center for Children, University of Chicago, Chicago.
- Cheslow, M. and J.K. Neels. 1980. Effect of Urban Development Patterns on Transportation Energy Use. *Transportation Research Record 764*, pp. 70-78.
- Chicago Area Transportation Study (CATS). 1959. Home Interview Data on Population and Related Trip Making Characteristics. Report No. 091, 17 June, Chicago.
- COMETRAVI. 1999. Diagnóstico de las condiciones del transporte y sus implicaciones sobre la calidad del aire. Volume 1 of of the *Estudio Integral de Transporte y Calidad del Aire en la Zona Metropolitana del Valle de México*, la Comisión Metropolitana de Transporte y Vialidad en coordinación con la Comisión Ambiental Metropolitana, Mexico City.

Comisión Nacional del Medio Ambiente (CONAMA). 2003. Región Metropolitana de Santiago. Evolución de la calidad del aire en Santiago 1997 – 2003. Área Descontaminación Atmosférica, December. Available at: <http://www.conama.cl/rm/568/article-29215.html>.

Comisión Nacional del Medio Ambiente (CONAMA). 2000. Políticas Ambientales Regionales para el Desarrollo Sustentable: Región Metropolitana. Santiago.

Comisión Nacional del Medio Ambiente (CONAMA). 1998. *Plan de Prevención y Descontaminación Atmosférica de la Región Metropolitana*, Santiago, March.

Companhia do Metropolitano de São Paulo. 1999. *Pesquisa Origem-Destino 1997 – Região Metropolitana de São Paulo: Síntese das Informações*.

Congress for the New Urbanism (CNU). 2001. *Charter of the New Urbanism*. Available at: <http://www.cnu.org/aboutcnu/index.cfm?formAction=charter> (last accessed 30 January 2005).

Crane, R. 1996. On form versus function: Will the new urbanism reduce traffic, or increase it? *Journal of Planning Education and Research*, Vol. 15, pp. 117-126.

Crane, R. 2000. The Influence of Urban Form on Travel: An Interpretive Review. *Journal of Planning Literature*, Vol. 15, No. 1, 2000, pp. 3-23.

Crane, R. and R. Crepeau. 1998. Does neighborhood design influence travel? A behavioral analysis of travel diary and GIS data, *Transportation Research D*, Vol. 3, No. 4, pp. 225-238.

Crane, R. and L.A. Schweitzer. 2003. Transport and Sustainability: The Role of the Built Environment. *Built Environment*, Vol. 29, No. 3, pp. 238-252.

Crilly, M., A. Mannis, and K. Morrow 1999. Indicators for Change: Taking a Lead. *Local Environment*, Vol. 4, No. 2, pp. 151–168.

Criterion Planners/Engineers, Inc. 2002. *Smart Growth Index Version 2.0: Indicator Dictionary*, prepared for the U.S. Environmental Protection Agency, October.

Crocco, J. 1950. Volumen, Distribución y Composición de la Población. In *Geografía Económica de Chile: Tomo II*. Corporación de Fomento de la Producción, Santiago.

Daly, H.E. 2002. Sustainable Development: Definitions, Principles, Policies. Invited Address, World Bank, Washington, DC, April 30.

Daly, H.E. and J. B. Cobb, Jr. 1989 (with contributions by C.W. Cobb). *For the Common Good: Redirecting the Economy toward Community, the Environment and a Sustainable Future*. Beacon Press, Boston.

de Cea, J., J.E. Fernández L., V. Dekock Ch., A. Soto O. 2004. Solving Network Equilibrium Problems on Multimodal Urban Transportation Networks with Multiple User Classes. Working paper, Departamento de Ingeniería de Transporte, Pontificia Universidad Católica de Chile, Santiago.

de Cea, J., J.E. Fernández L., V. Dekock Ch., A. Soto O., T.L. Friesz. 2003. ESTRAUS: A Computer Package for Solving Supply-Demand Equilibrium Problems on Multimodal Urban Transportation Networks with Multiple User Classes. Presented at the Annual Meeting of the Transportation Research Board, Washington, DC.

de Ramón, A. and J.M. Larraín. 1980. Urban Renewal, Rehabilitation, and Remodeling of Santiago, Chile. *Urbanization in the Americas: The Background in Comparative Perspective* (W. Borah, J. Hardoy, G. Stellar, Eds.), Proceedings of Section VII, The Process of Urbanization, International Congress of Americanists, Vancouver, 11-17 Aug, 1979, published by History Division, National Museum of Man, Ottawa, Canada.

Dear, M. and S. Flusty. 1998. Postmodern Urbanism. *Annals of the Association of American Geographers*, Vol. 88, No. 1, March, pp. 50-72.

Delucchi, M.A. 1997. The Annualized Social Cost of Motor-Vehicle Use in the U.S. Based on 1990-1991 Data: Summary of Theory, Data, Methods, and Results. *The Full Costs and Benefits of Transportation: Contributions to Theory, Method and Measurement* (D.L. Greene, D.W. Jones, M.A. Delucchi, Eds.). Springer, Berlin.

Díaz, G. 2004. Acciones Subsecretaría de Transportes. Presented at the International Seminar, *Opportunities for the Clean Development Mechanism in Transportation*, organized by the International Institute for Sustainable Development, at United Nations Economic Commission for Latin America and the Caribbean, Santiago, August.

Dickey, J.W. and J.P. Broderick. 1972. Toward a technique for a more exhaustive evaluation of urban area performance. *Environment and Planning*, Vol. 4, pp. 43-58.

Dieleman, F. M. Dijst, G. Burghouwt. 2002. Urban Form and Travel Behaviour: Micro-level Household Attributes and Residential Context. *Urban Studies*, Vol. 39, No. 3, pp. 507-527.

Dill, J. 2004. Measuring Network Connectivity for Bicycling and Walking. Paper Presented at the Annual Meeting of the Transportation Research Board, Washington, DC, January.

Ding, C. 1994. Impact Analysis of Spatial Data Aggregation on Transportation Forecasted Demand: A GIS Approach. *URISA Proceedings*. Annual Conference of the Urban and Regional Information Systems Association, 7-11 August, Milwaukee, pp. 362-375.

- Dirección de Estadística y Censos (DEC). 1960. *XIII Censo de Población: Serie A, Resumen del País*. Santiago.
- Dong, X., M. Ben-Akiva, J. Bowman, J. Walker. 2005. Moving from Trip-Based to Activity-Based Measures of Accessibility. *Transportation Research A* (forthcoming).
- Dubin, J.A. and D.L. McFadden. 1984. An Econometric Analysis of Residential Electric Appliance Holdings and Consumption. *Econometrica*, Vol. 52, No. 2, March, pp. 345-362.
- Economic Geography*. 1971. Volume 47, Issue Supplement: Comparative Factorial Ecology, June.
- Edwards, J.L. and J.L. Schofer. 1976. Relationships Between Transportation Energy Consumption and Urban Structure: Results of Simulation Studies. *Transportation Research Record* 599, pp. 52-59.
- EEA. 2002. *Towards an Urban Atlas: Assessment of Spatial Data in 25 European Cities and Urban Areas*. Environment Issue Report No. 30, European Environment Agency, Copenhagen.
- European Conference of Ministers of Transport (ECMT). 2004. *Assessment & Decision Making for Sustainable Transport*. Organization for Economic Cooperation and Development, Paris.
- Everitt, B.S. and G. Dunn. 2001. *Applied Multivariate Data Analysis*. Arnold, London.
- Ewing, R. 1995. Measuring Transportation Performance. *Transportation Quarterly*, Vol. 49, No. 1, Winter, pp. 91-104.
- Ewing, R. and R. Cervero. 2001. Travel and the Built Environment: A Synthesis. *Transportation Research Record 1780: Land Development and Public Involvement in Transportation*, TRB, National Research Council, Washington, DC, pp. 87-113.
- Ewing, R. R. Schieber, C. Zegeer. 2003. Urban Sprawl as a Risk Factor in Motor Vehicle Occupant and Pedestrian Fatalities. *American Journal of Public Health*, Vol. 93, No. 9, September, pp. 1541-1545.
- Farah, M., F. Aguirre, B. Gallardo. 1993. Comentarios Acerca del Comportamiento de las Personas que Realizan Viajes en Santiago, Valparaíso y Concepción. *Actas del VI Congreso Chileno de Ingeniería de Transporte* (J. de Cea and H. Malbrán, Eds.). Organized by SECTRA, Santiago, 25-28 October.
- Federal Highway Administration (FHWA). 2002. *Status of the Nation's Highways, Bridges, and Transit: 2002 Conditions and Performance Report*. United States Department of Transportation.

- Figueroa, J. 1996. 1929: La Ciudad Demostrativa. *Revista de Arquitectura* (Facultad de Arquitectura y Urbanismo, Universidad de Chile), No. 8, pp. 4-7.
- Gakenheimer, R. 1997. Sustainable Transport and Economic Development: A Comment. *Journal of Transport Economics and Policy*, Vol. XXXI, No. 3, September, pp. 331-334.
- Gakenheimer, R. 1999. Urban mobility in the developing world. *Transportation Research A*, Vol. 33, pp. 671-689.
- Gakenheimer, R. and C. Zegras. 2004. Drivers of Travel Demand in Cities of the Developing World. Appendix in *Mobility 2030: Meeting the Challenges to Sustainable Mobility*. Full Report of the Sustainable Mobility Project, World Business Council for Sustainable Development, Geneva.
- Galster, G.C. 1986. What is a neighborhood? An externality-space approach. *International Journal of Urban and Regional Research*, Vol. 10, pp. 243-263.
- Geurs, K.T. and J. Ritsema van Eck. 2001. Accessibility measures: review and applications. RIVM report 408505 006, National Institute of Public Health and the Environment, Bilthoven, The Netherlands, June.
- Geurs, K.T. and B. van Wee. 2004. Accessibility evaluation of land-use and transport strategies: review and research directions. *Journal of Transport Geography*, Vol. 12, pp. 127-140.
- Gilbert, G. and J.S. Dajani. 1974. Energy, Urban Form and Transportation Policy. *Transportation Research*, Vol. 8, pp. 267-276.
- Giovannini, E. 2004. Accounting Frameworks for Sustainable Development: What Have We Learnt? In *Measuring Sustainable Development: Integrated Economic, Environmental, and Social Frameworks*. Organization for Economic Cooperation and Development, Paris.
- Glaeser, E. 1998. Are Cities Dying? *The Journal of Economic Perspectives*, Vol., 12, Issue 2, Spring, pp. 139-160.
- Gobierno Regional Metropolitano (GoRe). 1995. *Estrategia de Desarrollo: 1995 – 2000*. Santiago, December.
- Godard, X. and L. Diaz Olvera. 2000. Poverty and Urban Transport: French Experience and Developing Cities. Background paper prepared for the World Bank Urban Transport Sector Review.

- Gómez-Ibáñez, J.A. 1997. Estimating Whether Transport Users Pay Their Way: The State of the Art. In *The Full Costs and Benefits of Transportation* (Greene, David L, Donald W. Jones and Mark A. Delucchi, Eds). Springer, Heidelberg.
- Gorsuch, R.L. 1983. *Factor Analysis*. Second Edition. Lawrence Erlbaum Associates, Hillsdale, NJ.
- Gosnell, H.F. and M.J. Schmidt. 1936. Factorial and Correlational Analysis of the 1934 Vote in Chicago. *Journal of the American Statistical Association*, Vol. 31, No. 195, September, pp. 507-518.
- Greene, D.L., D.W. Jones, M.A. Delucchi (Editors). 1997. *The Full Costs and Benefits of Transportation*. Springer, Heidelberg.
- Greenwald, M.J. 2003. The Road Less Traveled: New Urbanist Inducements to Travel Mode Substitution for Nonwork Trips. *Journal of Planning Education and Research*, Vol. 23, pp. 39-57.
- Greenwald, M.J. and M.G. Boarnet. 2001. Built Environment as Determinant of Walking Behavior: Analyzing Nonwork Pedestrian Travel in Portland, Oregon. *Transportation Research Record 1780: Land Development and Public Involvement in Transportation*, TRB, National Research Council, Washington, DC, pp. 33-42.
- Gustavson, K., S.C. Lonergan, J. Ruitenbeek. 1999. Selection and modeling of sustainable development indicators: a case study of the Fraser River Basin, British Columbia. *Ecological Economics*, Vol. 28, pp. 117–132.
- Gwilliam, K. 1997. Sustainable Transport and Economic Development. *Journal of Transport Economics and Policy*, Vol. XXXI, No. 3, September, pp. 325-330.
- Hagerstrand, T. 1970. What About People in Regional Science? *Papers of the Regional Science Association*, Vol. 24, pp. 7-21.
- Hall, P. and U. Pfeiffer. 2000. *Urban Future 21: A Global Agenda for Twenty-First Century Cities*, E&FN Spon, London.
- Hall, R.P. 2002. *Introducing the Concept of Sustainable Transportation to the U.S. DOT through the Reauthorization of TEA-21*. Masters Thesis submitted to the Engineering Systems Division and the Department of Civil and Environmental Engineering in Partial Fulfillment of the Requirements for the Degrees of Master of Science in Technology and Policy and Master of Science in Civil and Environmental Engineering, Massachusetts Institute of Technology, June.
- Hall, R. P., and J. M. Sussman. 2003. Sustainable Transportation: A Strategy for System Change. Working Paper, Massachusetts Institute of Technology, Cambridge, MA.

Hamilton, B.W. 1982. Wasteful Commuting. *The Journal of Political Economy*, Vol. 90, No. 5, October, pp. 1035-1053.

Hamilton, K. and M. Clemens. 1999. "Genuine Savings Rates in Developing Countries." *The World Bank Economic Review*, Volume 13, Number 2, May, pp. 333-356.

Handy, S. 1992a. How Land Use Patterns Affect Travel Patterns: A Bibliography. CPL Bibliography No. 279, Council of Planning Librarians, Chicago.

Handy, S. 1992b. Regional Versus Local Accessibility: Neo-Traditional Development and Its Implications for Non-work Travel. *Built Environment*, Vol. 18, No. 4, pp. 253-267.

Handy, S. 1993. Regional Versus Local Accessibility: Implications for Nonwork Travel. *Transportation Research Record 1400*, pp. 58-66.

Handy, S. 1996. Methodologies for Exploring the Link Between Urban Form and Travel Behavior. *Transportation Research D*, Vol. 1, No. 2, pp. 151-165.

Handy, S.L. and K.J. Clifton. 2001. Local shopping as a strategy for reducing automobile travel. *Transportation*, Vol. 28, pp. 317-346.

Handy, S. L., K.J. Clifton, and J. Fisher. 1998. *The Effectiveness of Land Use Policies as a Strategy for Reducing Automobile Dependence: A Study of Austin Neighborhoods* (No. SWUTC/98/465650 -1). Southwest Region University Transportation Center, Center for Transportation Research, University of Texas at Austin, Austin, TX. ([http://www.des.ucdavis.edu/faculty/handy/Austin\\_Report.pdf](http://www.des.ucdavis.edu/faculty/handy/Austin_Report.pdf)).

Handy, S. and D. Niemeier. 1997. Measuring accessibility: an exploration of issues and alternatives. *Environment and Planning A*, Vol. 29, pp. 1175-1194.

Hanson, M. 1989. The motor vehicle dominated city as a non-sustainable urban form: Mexico City and Jakarta. *Computers, Environment and Urban Systems*, Vol. 13, No. 2, pp. 95-108.

Hanson, S. 1982. Determinants of Daily Travel-Activity Patterns: Relative Location and Sociodemographic Factors. *Urban Geography*, Vol. 3, No. 3, July-September, pp. 179-202.

Harris, B. 2001. Accessibility: Concepts and Applications. *Journal of Transportation and Statistics*, September/December, pp. 15-30.

Hawken, P., A. Lovins, L.H. Lovins. 1999. *Natural Capitalism: Creating the Next Industrial Revolution*. Little, Brown.

Haynes, K.E. 1971. Spatial Change in Urban Structure: Alternative Approaches to Ecological Dynamics. *Economic Geography*, Vol. 47, June, pp. 324-335.

Hardoy, J.E. and M.E. Langdon. Cities and Regional Thought in Argentina and Chile Between 1850 and 1930. *Urbanization in the Americas: The Background in Comparative Perspective* (W. Borah, J. Hardoy, G. Stellar, Eds.), Proceedings of Section VII, The Process of Urbanization, International Congress of Americanists, Vancouver, 11-17 Aug, 1979, published by History Division, National Museum of Man, Ottawa, Canada.

Häusler, A., M. Scherer-Lorenzen. 2002. Sustainable Forest Management in Germany: The Ecosystem Approach of the Biodiversity Convention Reconsidered. Results of the R+D-Project 800 83 001. Bundesamt für Naturschutz (BfN) German Federal Agency for Nature Conservation, Bonn.

Hausman, J., G. Leonard, D. McFadden. 1995. A utility-consistent, combined discrete choice and count data model Assessing recreational use losses due to natural resource damage. *Journal of Public Economics*, vol. 56, pp. 1-30.

Herrera-Ulloa, A., A. Chalres, S. Lluch-Cola, H. Ramírez-Aguirre, S. Hernández-Vázquez, A. Ortega-Rubio. 2003. A regional-scale sustainable development index: the case of Baja California Sur, Mexico. *International Journal of Sustainable Development and World Ecology*, Vol. 10, No. 4, December, pp. 353-360.

Herz, R. 1982. The Influence of Environmental Factors on Daily Behavior. *Environment and Planning A*, Vo. 14, pp. 1175-1193.

Hess, D.B. and P.M. Ong. 2002. Traditional Neighborhoods and Automobile Ownership. *Transportation Research Record: 1805*, pp. 35-44.

Hess, P.M., A.V. Moudon, M.G. Logsdon. 2001. Measuring Land Use Patterns for Transportation Research. *Transportation Research Record 1780: Land Development and Public Involvement in Transportation*, TRB, National Research Council, Washington, DC, pp. 17-24.

Heywood, J., M. Weiss, A. Schafer, S. Bassene, V. Natarajan. 2003. The Performance of Future ICE and Fuel Cell Powered Vehicles and Their Potential Fleet Impact. Massachusetts Institute of Technology, Laboratory for Energy and the Environment, Publication No. LFEE 2003-004 RP, Cambridge, MA, December.

Hidalgo, R. 2004. De los pequeños condominios a la ciudad vallada: las urbanizaciones cerradas y la nueva geografía social en Santiago de Chile (1990-2000). *EURE*, vol. 30, no. 91, December, pp. 29-52.

Hillier, B. and J. Hanson. 1984. *The Social Logic of Space*. Cambridge University Press, Cambridge, UK.

- Hillier, B. and A. Penn. 2004. Rejoinder to Carlo Ratti. *Environment and Planning B: Planning and Design*, Vol. 31, pp. 501-511.
- Hirt, S. 2003. Measuring Postmodernism: Placing Urban Planning Values in the Context of a Broader Cultural Values Transition. Paper presented at the 2003 Distinguished Faculty and Student Symposium: *Crossing Disciplinary Boundaries in the Urban and Regional Context*, March, Ann Arbor, Michigan, Available at: <http://www.caup.umich.edu/acadpgm/urp/utepsymposium/Publication/hirt.pdf> (Last Accessed 14 May).
- Hodge, G. 1963. Use and Mis-use of Measurement Scales in City Planning. *AIP Journal*, May, pp. 121.
- Hodge, R.A., P. Hardi, D. Bell. 1999. Seeing Change through the Lens of Sustainability. Background Paper for the Workshop "Beyond Delusion: Science and Policy Dialogue on Designing Effective Indicators of Sustainable Development," The International Institute For Sustainable Development, Costa Rica, 6-9 May.
- Hofer, A. 2003. *Karl Brunner y el urbanismo europeo en América Latina*. El Áncora Editores, Corporación La Candelaria, Bogotá, Colombia.
- Holton, R. 1958. The Distinction Between Convenience Goods, Shopping Goods, and Specialty Goods. *Journal of Marketing*, July, pp. 53-56.
- Holtzclaw, J., R. Clear, H. Dittmar, D. Goldstein, P. Haas. 2002. Location Efficiency: Neighborhood and Socioeconomic Characteristics Determine Auto Ownership and Use – Studies in Chicago, Los Angeles and San Francisco. *Transportation Planning and Technology*, Vol. 25, pp. 1–27.
- Horner, M.W. and A.T. Murray. 2002. Excess Commuting and the Modifiable Areal Unit Problem. *Urban Studies*, Vol. 39, No. 1, pp. 131-139.
- Hunt, J.D. Modeling Transportation Policy Impacts on Mobility Benefits and Kyoto-Protocol-Related Emissions. *Built Environment*, Vol. 29, No. 1, pp. 48-65.
- IBI Group. 2000. Greenhouse Gas Emissions from Urban Travel: Tool for Evaluating Neighborhood Sustainability. Healthy Housing and Communities Series Research Report, prepared for Canada Mortgage and Housing Corporation and Natural Resources Canada, February.
- Ingram, D.R. 1971. The Concept of Accessibility: A Search for an Operational Form. *Regional Studies*, Vol. 5, pp. 101-107.
- Ingram, G. 1998. Patterns of Metropolitan Development: What Have We Learned? *Urban Studies*, Vol. 35, No. 7, June, pp. 1019-1035.

Ingram, G. and Z. Liu. 1997. Motorization and the Provision of Roads in Countries and Cities. Policy Research Working Paper 1842, World Bank, Infrastructure and Urban Development Department, Washington, DC.

Ingram, G. and Z. Liu. 1998. Vehicles, Roads, and Road Use: Alternative Empirical Specifications. Policy Research Working paper 2036. World Bank, Infrastructure and Urban Development Department, Washington, DC.

Innes, J.E., D.E. Booher. 1999. Metropolitan Development as a Complex System: A New Approach to Sustainability. *Economic Development Quarterly*, Vol. 13, No. 2, May, pp. 141-156.

Instituto de Estudios Urbanos y Territoriales (IEUT). 2004. DIMSUD Synthesis Report: Towards Sustainable Urban Development in Santiago, Chile. Report prepared by the Catholic University of Chile for the Alliance for Global Sustainability project, *Designing, Implementing and Measuring Sustainable Urban Development*.

Instituto Nacional de Estadísticas (INE). 1992, 1982, 1970. Censo de población y vivienda. INE, Santiago, Chile. Summaries of this Census data for these years for the *comunas* of the Metropolitan Region provided to the autor by Loreto Guzmán, October, 2000.

Instituto Nacional de Estadísticas (INE). 2002. Censo de población, vivienda y hogar. INE, Santiago, Chile. Census data for 38 *comunas* of the Metropolitan Region, data summarized at the block level, provided to the author by INE, August, 2004.

Instituto Nacional de Estadística, Geografía e Informática (INEGI). 1999. Banco de Información Económica, Sector Comunicaciones y Transportes, Mexico, last Accessed October 1999: <http://www.inegi.gob.mx/economia/espanol/feconomia.html>.

Intendencia de la Región Metropolitana. 1989. *Estudio Base de Generación de Niveles de Ruido en Santiago: Resumen*. Santiago, August.

International Energy Agency (IEA). 2004. Transport Model developed for the World Business Council for Sustainable Development Sustainable Mobility Project. Model and documentation last accessed 19 May 2005 at: <http://wbcsd.org/plugins/DocSearch/details.asp?type=DocDet&ObjectId=MTE0Njc>.

Jamieson, G.B., W.K. Mackay, J.C.R. Latchford. 1967. Transportation and Land Use Structures. *Urban Studies*, Vol. 4, No. 3, November, pp. 201-217.

Janson, C.-G. 1980. Factorial Social Ecology: An Attempt at Summary and Evaluation. *Annual Review of Sociology*, Vol. 6, pp. 433-456.

Japanese International Cooperation Agency (JICA). 2004. *Plan Maestro de Transporte Urbano para el Área Metropolitana de Lima y Callao en la República del Perú*. Prepared by Yachiyo Engineering Co., Ltd. in association with Pacific Consultants International.

Jara-Díaz, S.R. and F.J. Martínez. 1999. On the specification of indirect utility and willingness to pay for discrete residential location models. *Journal of Regional Science*, Vol. 39 (4), pp. 675-688.

Jeon, C.M and A. Amekudzi. 2005. Addressing Sustainability in Transportation Systems: Definitions, Indicators, and Metrics. *Journal of Infrastructure Systems*, March, pp. 31-50.

Johnston, R.A., C.J. Rodier, J.E. Abraham, J.D. Hunt. 2001. Applying an Integrated Model to the Evaluation of Travel Demand Management Policies in the Sacramento Region: Year Two. Mineta Transportation Institute, College of Business, San Jose State University, San Jose, CA, September.

Jones, K.J. and W.C. Jones. 1970. Toward a Typology of American Cities. *Journal of Regional Science*, Vol. 10, No. 2, pp. 217-224.

*Journal of Transportation and Statistics: Special Issue on Methodological Issues in Accessibility*. 2001. Vol. 4, Nos. 2/3, September/December.

Kain, J-H. 2003. On Planning, Design, Decision-making and Implementation of Measures for Sustainable Urban Development. Chalmers University, Architecture, Working paper 030929.

Kain, J. 1967. Postwar Metropolitan Development: Housing Preferences and Auto Ownership. *The American Economic Review*, Vol. 57, No. 2 (May), pp. 223-234.

Kain, J. and M. Beesley. 1965. Forecasting Car Ownership and Use. *Urban Studies*, 2, No. 2, pp. 163-185.

Kain, J. & Z. Liu. 2002. Efficiency and Locational Consequences of Government Transport Policies and Spending in Chile. In *Chile: Political Economy of Urban Development* (E.L. Glaeser and J.R. Meyer, Eds.), John F. Kennedy School of Government, Harvard University, Cambridge.

Keiner, M., D. Salmerón, W. Schmid, I. Poduje. 2004. Urban Development in Southern Africa and Latin America. Chapter 1 in *From Understanding to Action: Sustainable Urban Development in Medium-Sized Cities in Africa and Latin America* (M. Keiner, C. Zegras, W. Schmid, D. Salmerón, Eds.), Springer, Dordrecht, The Netherlands.

Kennedy, C.A. 2002. A comparison of the sustainability of public and private transportation systems: Study of the Greater Toronto Area. *Transportation* 29, pp. 459-493.

Kenworthy, P. and F. Laube. 1999. Patterns of automobile dependence in cities: an international overview of key physical and economic dimensions with some implications for urban policy. *Transportation Research A*, Vol. 33, pp. 691-723.

Kenworthy, P. and F. Laube. 2001. Millennium Cities Database for Sustainable Transport. Produced for the International Union for Public Transport by the Institute for Sustainability and Technology Policy (ISTP) at Murdoch University, Perth, Australia.

Kenworthy, J.R., F.B. Laube, P. Newman, P. Barter, T. Raad, C. Poboorn, B. Guia Jr. 1999. *An International Sourcebook of Automobile Dependence in Cities, 1960-1990*. University Press of Colorado, Boulder.

Khattak, A.J. and D. Rodriguez. 2005. Travel behavior in neo-traditional neighborhood developments: A case study in USA. *Transportation Research Part A*, vol. 39, pp. 481-500.

Kim, K.-S. and J. Schneider. 1985. Defining Relationships Between Urban Form and Travel Energy. *Transportation Research Record No. 1049*, pp. 43-50.

Kitamura, R., T. Akiyama, T. Yamamoto, T. Golob. 2001. Accessibility in a Metropolis: Toward a Better Understanding of Land Use and Travel. *Transportation Research Record 1780*, pp. 64-75.

Kitamura, R., Mokhtarian, P. L. and Laidet, L. 1997. A micro-analysis of land use and travel in five neighborhoods in the San Francisco Bay Area. *Transportation*, Vol. 24, pp. 125-158.

Kitchen, P. 2001. An approach for measuring urban deprivation change: the example of East Montreal and the Montreal Urban Community, 1986-96. *Environment and Planning A*, Vol. 33, pp. 1901-1921.

Klöpffer, W. 2002. Life-Cycle Based Methods for Sustainable Product Development. Paper presented at AIST/IIASA/UNEP Workshop on Life Cycle Approaches to Sustainable Consumption. Laxenburg, Austria, 22 November.

Kockelman, K.M. 1997. Travel Behavior as Function of Accessibility, Land Use Mixing, and Land Use Balance: Evidence from San Francisco Bay Area. *Transportation Research Record 1607*, pp. 116-125.

Korten, D.C. 1995. *When Corporations Rule the World*, Kumarian Press and Berrett-Koehler Publishers, West Hartford and San Francisco.

KPMG Peat Marwick LLP. 2000. *Data Collection and Modeling Requirements for Assessing Transportation Impacts of Micro-Scale Design: Executive Summary*. DTFH61-

95-C-00168, Task Order No. 7, Prepared for U.S. Federal Highway Administration under subcontract to Parsons Brinckerhoff Quade & Douglas, Inc., McLean, VA, June.

Krakauer, D. 2003. An Introduction to Form and Function. Paper presented at *The Integration of Form and Function*, A Joint Workshop of the Santa Fe Institute and the Collegium Budapest Institute for Advanced Study, Collegium Budapest, Institute for Advanced Study, November 16-19; last accessed on 13 May 2005 at: <http://discuss.santafe.edu/formandfunction/introduction>.

Krizek, K.J. 2003a. Neighborhood services, trip purpose, and tour-based travel. *Transportation*, Vol. 30, pp. 387–410.

Krizek, K.J. 2003b. Operationalizing Neighborhood Accessibility for Land Use-Travel Behavior Research and Regional Modeling. *Journal of Planning Education and Research*, Vol. 22, pp. 270-287.

Krizek, K.J. 2003c. Residential Relocation and Changes in Urban Travel. *Journal of the American Planning Association*, Vol. 69, No. 3, Summer, pp. 265-281.

Kubinger, K. 2003. On artificial results due to using factor analysis for dichotomous variables, *Psychology Science*, Volume 45, 2003 (1), pp. 106-110 ([http://www.psychology-science.com/1-2003/pdf\\_06.pdf](http://www.psychology-science.com/1-2003/pdf_06.pdf)).

Kwok, R, and A. Yeh. 2004. The use of modal accessibility gap as an indicator for sustainable transport development, *Environment and Planning A*, volume 36, pages 921 ^ 936

LABTUS. 2004. Location Efficiency and Transit-Oriented Development: A Potential CDM Option in Santiago de Chile. Final Report. Prepared for the International Institute for Sustainable Development (IISD), Winnipeg, Manitoba, by the Universidad de Chile, Laboratorio de Modelamiento del Transporte y Uso de Suelo, Santiago de Chile, October. Available at: [http://www.iisd.org/climate/south/ctp\\_documents.asp](http://www.iisd.org/climate/south/ctp_documents.asp).

Lanfranco, P., R Quijada, L Sagaris, R. Alvarez, E. Rivera, C. Quijada, D. Fuccaro, R. Planzer, G. Montero, L. Basso, P. Donoso, R. Fernandez, C. Garrido, C. Palma. 2003. *Muevete por tu ciudadana: una propuesta ciudadana de transporte con equidad*. Ciudad Viva, Santiago, Chile.

Larraín P. and H. Toledo. 1990. Diferencias Espaciales en los Niveles de Bienestar Social en el Gran Santiago: Implicancias conceptuales, metodológicas y políticas. *EURE Revista Latinoamericana de Estudios Urbano Regionales*, Vol. XVI, No. 49, pp. 33 – 49.

Lautso, K., and Toivanen, S. 1999. The SPARTACUS System for Analyzing Urban Sustainability. Paper presented at the 79<sup>th</sup> Annual Meeting of the Transportation Research Board, Washington, DC, January.

le Clerq, F. and L. Bertolini. 2003. Achieving Sustainable Accessibility: An Evaluation of Policy Measures in the Amsterdam Area. *Built Environment*, Vol. 29, No. 1, pp. 36-47.

Lee, C.-M. and K.-H. Ahn. 2003. Is Kentlands Better than Radburn? The American Garden City and New Urbanist Paradigms. *Journal of the American Planning Association*, Vol. 69, No. 1, Winter, pp. 50-71.

Lee, R., P. Wack., E. Jud, T. Munroe, J. Anguiano, T. Keith. 2003. *Toward Sustainable Transportation Indicators for California*. Mineta Transportation Institute College of Business, San José State University, San Jose, CA, August.

Lepeley C., F. and L.A. Cifuentes L. 1997. Emisiones de los Vehículos Livianos a Gasolina en Santiago. In *Actas del VIII Congreso Chileno de Transporte* (Gálvez, T., M. Munizaga, Eds.). Santiago, November, pp. 159-173.

Levine, J. 1998. Rethinking Accessibility and Jobs-Housing Balance. *Journal of the American Planning Association*, Vol, 64, No. 2, Spring, pp. 133-149.

Levett, R. 1998. Footprinting: a great step forward, but tread carefully – A response to Mathis Wackernagel. *Local Environment*, Vol. 3, No. 1, pp. 67-74.

Levinson, H. and F.H. Wynn. 1963. Effects of Density on Urban Transportation Requirements. *Highway Research Record No. 2: Community Values as Affected by Transportation*. Washington, DC, Highway Research Board, pp. 38-64.

Limanond, T. and D. Niemeier. 2003. Accessibility and mode-destination choice decisions: exploring travel in three neighborhoods in Puget Sound, WA. *Environment and Planning B*, vol. 30, pp. 219-238.

Litman, T. 2001. Sustainable Transport Indicators. Victoria Transport Policy Institute, Victoria, BC, 14 February.

Litman, T. 2003. Measuring Transportation: Traffic, Mobility and Accessibility. *ITE Journal*, Vol. 73, No. 10, October, pp. 28-32.

Lowell, R. 1973. *For Lizzie and Harriet*. Farrar, Straus and Giroux, New York.

LUTRAQ. 1996. *Making the Land Use Transportation Air Quality Connection: Analysis of Alternatives: Vol. 5*. Prepared by Cambridge Systematics and Parsons, Brinckerhoff, Quade & Douglas for 1,000 Friends of Oregon, Portland, May.

Lynch, K. 1984. *Good City Form*. MIT Press, Cambridge, MA. (First published in 1981 as *A Theory of Good City Form*).

Lyons, T.J., J. Kenworthy, C. Moy, F. dos Santos. 2003. An international urban air pollution model for the transportation sector. *Transportation Research Part D*, Vol. 8, pp. 159-167.

- Maat, K., B. van Wee, D. Stead. 2005. Land use and travel behaviour: expected effects from the perspective of utility theory and activity-based theories. *Environment and Planning B: Planning and Design*, Vol. 32, pp. 33-46.
- Mackie, P.J., M. Wardman, A.S. Fowkes, G. Whelan, J. Nellthorp and J.J. Bates. 2003. Values of travel time savings in the UK. Report to Department of Transport by the Institute for Transport Studies, University of Leeds.
- Manning, F. 1986. Selectivity Bias in Models of Discrete and Continuous Choice: An Empirical Analysis. *Transportation Research Record 1085*, pp. 58-62.
- Marble, D.F. 1959. Transport Inputs at Urban Residential Sites. *Papers and Proceedings of the Regional Science Association*, Vol. 5, pp. 253-266.
- Martínez, F. 1995. Access: the transport-land use economic link. *Transportation Research B*, Vol. 29, No. 6, pp. 789-796.
- Martínez, F. and C. Araya. 2000a. A Note on Trip Benefits in Spatial Interaction Models. *Journal of Regional Science*, Vol. 40, No. 4, pp. 789-796.
- Martínez, F. and C. Araya. 2000b. Transport and land-use benefits under location externalities. *Environment and Planning A*, Vol. 32, No. 9, pp. 1611-1624.
- Massachusetts Institute of Technology-City Design and Development Group (MIT-CDD). 2003. *Santiago Urban Planning Studio: Sustainable San Joaquín*. Department of Urban Studies and Planning, Cambridge, MA.
- Matas, J. & P. Balbontin. 1987. *Las Ciudades de la Ciudad*. Santiago, March.
- McCormack, E., G.S. Rutherford, M. Wilkinson. 2001. Travel Impacts of Mixed Land Use Neighborhoods in Seattle, Washington. *Transportation Research Record 1780*, pp. 25-32.
- McFadden, D. 1978. Modelling the Choice of Residential Location. Chapter 3 in *Spatial Interaction Theory and Planning Models* (A. Karlqvist, L. Lundqvist, F. Snickars, J. Weibull, Eds.). Studies in Regional Science and Urban Economics, Volume 3. North-Holland, New York.
- McFadden, D. 1986. The Choice Theory Approach to Market Research. *Marketing Science*, Vol. 5, No. 4, Autumn, pp. 275-297.
- McGuckin, N. and N. Srinivasan. 2003. *Journey to Work Trends in the United States and its Major Metropolitan Areas 1960 – 2000*. Publication No. FHWA -EP-03-058, Prepared for the US Department of Transportation Federal Highway Administration, Office of Planning, June, (<http://www.fhwa.dot.gov/ctpp/jtw/>).

- McNally, M. and A. Kulkarni. 1997. Assessment of Influence of Land Use-Transportation System on Travel Behavior. *Transportation Research Record 1607*, pp. 105-115.
- McNally, M. and S. Ryan. 1993. A Comparative Assessment of Travel Characteristics for Neo-Traditional Developments. Paper presented at the 72<sup>nd</sup> Annual Meeting of the Transportation Research Board, Washington, DC.
- Meadows, D.L (Editor). 1977. *Alternatives to Growth-I: A Search for Sustainable Futures*. Ballinger, Cambridge.
- Meadows D.H., D.L. Meadows, J. Randers, and W.W. Behrens. 1972. *The Limits to Growth*. Universe Books, Potomac Associates, New York.
- Meier, K.J. and J.F. Brudney. 2002. *Applied Statistics for Public Administration*. Fifth Edition. Wadsworth/Thomson, Belmont, CA.
- Merriam-Webster, Inc. 1996. *Merriam-Webster's Collegiate Dictionary*. Tenth Edition, Springfield, MA.
- Metro, S.A. 2001. *Statistical Appendix 2001*. Metro de Santiago, Santiago.
- Meurs, H. and R. Haaijer. 2001. Spatial structure and mobility. *Transportation Research Part D*, Vol. 6, pp. 429-446.
- Meyer, D.R. 1971. Factor Analysis Versus Correlation Analysis: Are Substantive Interpretations Congruent? *Economic Geography*, Vol. 47, June, pp. 336-343.
- Meyer, M. and E. Miller. 2001. *Urban Transportation Planning: A Decision-Oriented Approach*. Second Edition. McGraw-Hill, New York.
- Miller, E.J. and A. Ibrahim. 1998. Urban Form and Vehicular Travel: Some Empirical Findings. *Transportation Research Record 1617*, pp. 18-27.
- Mills, E.S. and C.S. Simmons. 2001. Evolution of the Chicago Landscape: Population Dynamics, Economic Development, and Land Use Change. Chapter 11 in *Growing Populations, Changing Landscapes: Studies from India, China and the United States*. National Academy Press, Washington, DC.
- Ministerio de Planificación y Cooperación (MIDEPLAN). 2003. CASEN. <http://www.mideplan.cl/casen/>.
- Ministerio de Planificación y Cooperación (MIDEPLAN). 2005. Indicadores. Last Accessed 28 May 2005 at: [http://www.mideplan.cl/publico/indicadores\\_archivo.php?catind=4](http://www.mideplan.cl/publico/indicadores_archivo.php?catind=4)

- Minken, H., D. Jonsson, S. Shepherd, T. Jarvi, T. May, M. Page, A. Pearman, P. Pfaffenbichler, P. Timms, A. Vold. 2003. *Developing Sustainable Land Use and Transport Strategies: A Methodological Guidebook*. Deliverable 14 of PROSPECTS, Funded by the European Commission 5<sup>th</sup> Framework EESD, published by the Institute of Transport Economics, Oslo, Norway.
- Morris, R.L. 1969. Transportation Planning for New Towns. *Highway Research Record No. 293: Transportation Systems Planning*, pp. 104-116.
- Morrison, A. 1992. *The Tramways of Chile: 1858 – 1978*. Bonde Press, New York.
- Moudon, A.V. 1992. The Evolution of Twentieth-Century Residential Forms: An American Case Study. Chapter 7 in *Urban Landscapes: International Perspectives* (Whitehead, J.W.R and P.J. Larkham, Eds.). Routledge, London and New York.
- Muñoz, L.M. 1937. La Transformación de las ciudades chilenas. *Zig Zag*, No. 12 (as cited by Hofer, 2003).
- Neumayer, E. 2000. On the methodology of ISEW, GPI and related measures: some constructive suggestions and some doubt on the ‘threshold’ hypothesis. *Ecological Economics*, Vol. 34, pp. 347–361.
- Neumayer, E. 2003a. Sustainability and well-being indicators. Draft paper prepared for UNU-WIDER, July.
- Neumayer, E. 2003b. *Weak versus Strong Sustainability: Exploring the Limits of Two Opposing Paradigms*. Second Edition. Edward Elgar, Cheltenham, UK.
- Newman, P. 2000. Promoting Sustainable Urban Change. *Sustainable Development Case Studies: Studies in cities and rural sustainability with a focus on the Asian region*. ISTP, Murdoch University, Available at: [http://www.istp.murdoch.edu.au/publications/e\\_public/Case%20Studies\\_Asia/susturbc/susturbc.htm#Heading4](http://www.istp.murdoch.edu.au/publications/e_public/Case%20Studies_Asia/susturbc/susturbc.htm#Heading4).
- Newman, P. and J. Kenworthy. 1980. Public and private transport in Australian cities: I. An analysis of existing patterns and their energy implications. *Transport Policy and Decision Making*, Vol. 1, pp. 133-148.
- Newman, P. & J. Kenworthy. 1989. *Cities and Automobile Dependence: An International Sourcebook*. Gower Publishing, Brookfield, VT.
- Niemeier, D. 1997. Accessibility: an evaluation using consumer welfare. *Transportation*, Vol. 24, pp. 377-396.

- Northern Illinois Planning Commission (NIPC). 1995. Census data and digital files provide to the author, July.
- Ocken, R.L. 1994. *The Relationship Between Site Design and Travel Behavior*. CPL Bibliography 312, Council of Planning Librarians, Chicago.
- OECD. 1979. *Urban Environmental Indicators*. Organization for Economic Cooperation and Development, Paris.
- OECD. 1996. *Pollution Prevention and Control: Environmental Criteria for Sustainable Transport*. Report on Phase 1 of the Project on Environmentally Sustainable Transport (EST), Organization for Economic Cooperation and Development, Paris.
- OECD. 1997. *Better Understanding Our Cities: The Role of Urban Indicators*. Organization for Economic Cooperation and Development, Paris.
- OECD. 1999. *The Economic and Social Implications of Sustainable Transportation: Proceedings from the Ottawa Workshop*. Organization for Economic Cooperation and Development, Environment Directorate, Working Party on Pollution Prevention and Control, Working Group on Transport, Paris.
- OECD. 2002. *OECD Guidelines Towards Environmentally Sustainable Transport*. Paris.
- Orski, K. 1974. The Potential for Fuel Conservation: The Case of the Automobile. *Transportation Research*, Vol. 8, pp. 247-257.
- Orski, K. 1999. *International Mobility Observatory: Window on the World of Transportation Innovation*. Cambridge, MA, Cooperative Mobility Program, MIT.
- Ortúzar, J. de D. 2001. On the development of the nested logit model. *Transportation Research Part B*, Vol. 35, pp. 213-216.
- Ortúzar, J. de D., A.M. Ivelic, H. Malbrán, A. Thomas. 1993. The 1991 Great Santiago origin-destination survey: methodological design and main results. *Traffic Engineering and Control*, 34, pp. 362-368.
- Ortúzar, J. de D. and L.G. Willumsen. 2001. *Modeling Transport*. Third Edition, Wiley.
- Ory, D. and P. Mokhtarian. 2005. When is getting there half the fun? Modeling the liking for travel. *Transportation Research Part A*, vol. 39, pp. 97–123.
- Parrochia B., J. and M.I. Pavez R. Undated. *El Plan Tridimensional de Ordenamiento Territorial y la Región Metropolitana de Santiago 1960-2000*. Report of the Departamento de Urbanismo, Facultad de Arquitectura y Urbanismo, Universidad de Chile, last accessed April, 2005 at: [mazinger.sisib.uchile.cl/repositorio/lb/arquitectura\\_y\\_urbanismo/pavezmi01/entrada.html](http://mazinger.sisib.uchile.cl/repositorio/lb/arquitectura_y_urbanismo/pavezmi01/entrada.html).

Parsons Brinckerhoff Quade & Douglas, Inc. (PBQD). 2000. Data Collection and Modeling Requirements for Assessing Transportation Impacts of Micro-Scale Design. Executive Summary. DTFH61-95-C-00168, Task Order No. 7, prepared for the U.S. Federal Highway Administration, June.

Pas, E. 1978. An empirical comparison of zonal, household and personal models of home-based trip generation. *Traffic Engineering and Control*, February, pp. 64-68.

Peake, S. and S. Hope. 1994. Sustainable mobility in context: Three transport scenarios for the UK. *Transport Policy*, Vol. 1, No. 3, pp. 195-207.

Perelman, L.J. 1980. Speculations on the Transition to Sustainable Energy. *Ethics*, Vol. 90, No. 3, pp. 392-416.

Pickrell, D. 1992. A Desire Named Streetcar: Fantasy and Fact in Rail Transit Planning. *Journal of American Planning Association*, 58, No. 2, Spring, pp. 158-176.

Pickrell, Don. 1999. Transportation and Land Use. In *Essays in Transportation Economics and Policy: A Handbook in Honor of John R. Meyer* (J.A. Gómez-Ibáñez, W. B. Tye, C. Winston, Eds.). Brookings Institution Press, Washington, DC.

Pirie, G.H. 1979. Measuring accessibility: a review and proposal. *Environment and Planning A*, vol. 11, pp. 299-312.

Pisarski, A. 1991. "Overview" in Chapter 1 of *Transportation, Urban Form, and the Environment: Proceedings of a Conference*. Special Report 231, Transportation Research Board, National Research Council, Washington, DC.

Pitcher, A. 1977. Sustainable Society – Ethics and Economic Growth. *Journal of Religion*, Vol. 57, No. 4, pp. 426-428.

Portney, K.E. 2003. *Taking Sustainable Cities Seriously: Economic Development, the Environment, and Quality of Life in American Cities / Kent E. Seriously*. MIT Press, Cambridge.

Preacher, K.J. and R.C. MacCallum. 2003. Repairing Tom Swift's Electric Factor Analysis Machine. *Understanding Statistics*, Vol. 2, No. 1, pp. 13-43.

Price, D.O. 1942. Factor Analysis in the Study of Metropolitan Centers. *Social Forces*, Vol. 20, No. 4, May, pp. 449-455.

Priest, D.E. 1982. Urban Village Concept: General Background. *Transportation Energy Conservation Through Land Use Planning: Conference Report*. DOT-I-82-50. Washington, DC, prepared by the Transportation Research Board for the Federal Highway Administration, U.S. Department of Transportation, pp. 41-44.

- Puelma, R. 1943. *Arenas del Mapocho*. Third Edition. Beuvedráis Editores, Santiago, Chile.
- Pushkarev, B. and J. Zupan. 1977. *Public Transportation and Land Use Policy*. Indiana University Press.
- Quiroga M., R. 2001. Indicadores de sostenibilidad ambiental y de desarrollo sostenible: estado del arte y Perspectivas. Manuales No. 16, UN CEPAL, División de Medio Ambiente y Asentamientos Humanos, Santiago de Chile, September.
- Rajamani, J. C. Bhat, S. Handy, G. Knaap, Y. Song. Assessing Impact of Urban Form Measures on Nonwork Trip Mode Choice After Controlling for Demographic and Level-of-Service Effects. *Transportation Research Record 1831*, 2003, pp. 158-165.
- Ramming, M.S. 1994. A Consumption-Based Accessibility Index of Transportation and Land Use. Thesis towards the Masters of Science in Transportation, Department of Civil and Environmental Engineering, Massachusetts Institute of Technology, Cambridge.
- RAND Europe, R. Gakenheimer, C. Zegras. 2003. Passenger and Freight Transport Demand: Final Report. Prepared for Workstreams 5 & 6 of the Sustainable Mobility Project, World Business Council for Sustainable Development, Geneva, 25 September.
- Ratti, C. 2004. Rejoinder to Hillier and Penn. *Environment and Planning B: Planning and Design*, Vol. 31, pp. 513-516.
- Ratti, C. 2004b. Space syntax: some inconsistencies. *Environment and Planning B: Planning and Design*, Vol. 31, pp. 487-499.
- Rawls, J. 1971. *A Theory of Justice*. Harvard University Press. Cambridge, MA.
- Real Estate Research Corporation (RERC). 1974a. *The Costs of Sprawl: Detailed Cost Analysis*. Prepared for the Council on Environmental Quality, Department of Housing and Urban Development, Environmental Protection Agency, Washington, DC, April.
- Real Estate Research Corporation (RERC). 1974b. *The Costs of Sprawl: Literature Review and Bibliography*. Prepared for the Council on Environmental Quality, Department of Housing and Urban Development, Environmental Protection Agency, Washington, DC, April.
- Reeder, L. G. 1956. Social Differentials in Mode of Travel, Time and Cost in the Journey to Work. *American Sociological Review*, Vol. 21, No. 1, February, pp. 56-63.
- Rees, P.H. 1971. Factorial Ecology: An Extended Definition, Survey, and Critique of the Field. *Economic Geography*, Vol. 47, June, pp. 220-233.

- Rees, W. 1997. Is 'Sustainable City' an Oxymoron? *Local Environment*, Vol. 2, No. 3, pp. 303-310.
- Replogle, M. 1987. Sustainable Transportation Strategies for Third World Development. Paper prepared for presentation to Conference Session on Human-Powered Transportation and Transportation Planning for Developing Countries, 67<sup>th</sup> Annual Meeting (1988) of the Transportation Research Board, Washington, DC.
- Replogle, M. 1989. Transportation Strategies for Sustainable Development. Paper prepared for presentation at the 5th World Conference on Transport Research, Yokohama, Japan, July 10-14.
- Replogle, M. 1991. Sustainability: A Vital Concept for Transportation Planning and Development. *Journal of Advanced Transportation*, Vol. 25, No. 1, pp. 3-18.
- Revista de Arquitectura*. 1996. Facultad de Arquitectura y Urbanismo, Universidad de Chile, No. 8.
- Rienstra, S. and R. Piers. 2000. Targets and Their Translation to Lower Scale Levels. *Built Environment*, Vol. 26, No. 3, pp. 167-196.
- Røe, P.G. 1999. Intra-urban travel and spatial-structural constraints: An investigation of travel and activity patterns in 30 residential areas in Oslo. Paper presented at the XIII AESOP Congress, Bergen, Norway, 7-11 July.
- Robson, B.T. 1969. *Urban Analysis: A Study of City Structure with Special Reference to Sunderland*. Cambridge, Cambridge University Press.
- Rodríguez, D. and J. Joo. 2004. The relationship between non-motorized mode choice and the local physical environment. *Transportation Research Part D*, 9, pp. 151-173.
- Rosenbaum, A. and B. Koenig. 1997. Evaluation of Modeling Tools for Assessing Land Use Policies and Strategies. Report prepared for Office of Mobile Sources, U.S. Environmental Protection Agency, Ann Arbor, MI, August.
- Ryan, S., J. Throgmorton. 2003. Sustainable Transportation and Land Development on the Periphery: A Case Study of Freiburg, Germany and Chula Vista, California. *Transportation Research: Part D: Transport and Environment*, Vol. 8, No. 1, January, pp. 37-52.
- Sabatini, F. 2000. Reforma de los mercados de suelo en Santiago, Chile: efectos sobre los precios de la tierra y la segregación residencial. *EURE Revista Latinoamericana de Estudios Urbano Regionales*. Vol. XXVI, No. 77, May, pp. 49-80.
- Sabatini, F. and F. Soler. 1995. Paradoja de la Planificación Urbana en Chile. *Revista EURE*, Vol. XXI, No. 62, April, pp. 61-73.

Sammons, R. and P. Hall, 1977. Urban Structure and Modal Split in the Journey to Work. *Urban Studies*, 14, pp. 1-9.

Santana, R. 1995. Evaluación de las Emisiones de Ruido del Sistema de Escape de Vehículos Diesel en la Región Metropolitana. *Actas del Séptimo Congreso Chileno de Ingeniería de Transporte* (Martínez, F.J., Ed.). Santiago, October, pp. 510-521.

*Savings and Loans News*. 1973. "Balancing Profit and the Environment: Three PUDs Show the Way," February, pp. 56-63.

Sawicki, D. and P. Flynn. 1996. Neighborhood Indicators. *Journal of the American Planning Association*, Vol. 62, Issue 2, Spring, pp. 165-184.

Schafer, A. 2000. Regularities in Travel Demand: An International Perspective. *Journal of Transportation and Statistics*, December, pp. 1-31.

Schimek, P. 1997. *Understanding the Relatively Greater Use of Public Transit in Canada Compared to the USA*. Cambridge, MA, unpublished PhD dissertation, Department of Urban Studies and Planning, MIT, June.

Schipper, L. 1996. Sustainable Transport: What It is, and Whether It Is. Abstract of address at the OECD International Conference, *Towards Sustainable Transportation*, Vancouver Canada, 24-27 March, last accessed 16 April 2004 at: <http://www.ecoplan.org/vancouver/papers.htm>.

Secretaría de Tránsito y Transporte (STT). 2005. *Estadísticas*. Alcaldía Mayor de Bogotá, DC. Department web site last accessed 29 May 2005 at: [http://www.transitobogota.gov.co/categoria.asp?cat\\_id=222](http://www.transitobogota.gov.co/categoria.asp?cat_id=222).

SECTRA. 1992a. *Encuesta Origen Destino de Viajes del Gran Santiago 1991*. Comisión de Planificación de Inversiones en Infraestructura de Transporte, Santiago.

SECTRA. 1992b. Greater Santiago Origin-Destination Survey. Provided to the author by SECTRA in 2001.

SECTRA. 2002. Greater Santiago Origin-Destination Survey. Provided to the author by SECTRA in 2004.

SECTRA. 2004. *Mobility Survey 2001: Executive Report*. Pontificia Universidad Católica de Chile and Gobierno de Chile, Santiago.

SECTRA, 2005. Individual consultant reports on the Origin-Destination Surveys for each city, available (as of 1 June 2005), for the medium sized cities at: [http://www.sectra.cl/contenido/planificacion\\_sistema\\_transporte/sistema\\_transpor\\_urban\\_o/ciudades\\_tamano\\_intermedio.htm](http://www.sectra.cl/contenido/planificacion_sistema_transporte/sistema_transpor_urban_o/ciudades_tamano_intermedio.htm); for Valparaíso at:

[http://www.sectra.cl/contenido/planificacion\\_sistema\\_transporte/sistema\\_transpor\\_urban\\_o/gran\\_valparaiso.htm](http://www.sectra.cl/contenido/planificacion_sistema_transporte/sistema_transpor_urban_o/gran_valparaiso.htm); for Concepción at:  
[http://www.sectra.cl/contenido/planificacion\\_sistema\\_transporte/sistema\\_transpor\\_urban\\_o/gran\\_concepcion.htm](http://www.sectra.cl/contenido/planificacion_sistema_transporte/sistema_transpor_urban_o/gran_concepcion.htm).

Seed, J. 1976. Sustainable urban structure. *Architectural Design*, Vol. XLVI, September, pp. 564-566.

Sen, A. 1998. Human Development and Financial Conservatism. *World Development*, Vol. 26, No. 4, pp. 733-742.

Sen, A. 2002. What Can Johannesburg Achieve? Distributed by *New Perspectives Quarterly*, Global Editorial Services, Nobel Laureates  
([http://www.digitaInpq.org/global\\_services/nobel%20laureates/08-13-02.html](http://www.digitaInpq.org/global_services/nobel%20laureates/08-13-02.html)).

Serageldin, I. 1996. Sustainability and the wealth of nations: first steps in an ongoing journey. Environmentally Sustainable Development Studies and Monographs Series No. 5, World Bank, Washington, D.C.

Sermons, M.W. and F.S. Koppelman. 1998. Factor Analytic Approach to Incorporating Systematic Taste Variation into Models of Residential Location Choice. *Transportation Research Record 1617*, pp. 194-202.

Shen, Q. 1998. Location characteristics of inner-city neighborhoods and employment accessibility of low-wage workers. *Environment and Planning B: Planning and Design*, Vol. 25, pp. 345-365.

Sistema Nacional de Información Ambiental (SiNIA). 2004. Lista indicadores por Región. Región: Metropolitana. Web site last accessed 22 April 2004:  
<http://www.sinia.cl/indicadores/index.php?pag=region&r=RM>.

Skamris, M.K. and B. Flyvbjerg. 1997. Inaccuracy of traffic forecasts and cost estimates on large transport projects. *Transport Policy*, 4, No. 3, pp. 141-146.

Small, K.A. 1980. Energy Scarcity and Urban Development Patterns. *International Regional Science Review*, 5, Winter, pp. 97-118.

Small, K.A. and H.S. Rosen. 1981. Applied Welfare Economics with Discrete Choice Models. *Econometrica*, Vol. 49, pp. 105-130.

Small, K.A. and C. Winston. 1999. The Demand for Transportation: Models and Applications. Chapter 2 in *Essays in Transportation Economics and Policy: A Handbook in Honor of John R. Meyer* (J. Gómez-Ibáñez, W. Tye, C. Winston, Eds), Brookings Institution Press, Washington, DC.

- Smith, M.A. 1998. Painting by Numbers: Mathematical Models of Urban Systems. *Environment and Planning B*, Vol., pp. 483-493.
- Smith, R. 2004. A Capital-based Sustainability Accounting Framework for Canada. In *Measuring Sustainable Development: Integrated Economic, Environmental, and Social Frameworks*. Organization for Economic Cooperation and Development, Paris.
- Smith, R. and R. Walker. 1994. The role of performance indicators in housing management: a critique. *Environment and Planning A*, Vol. 26, No. 4, pp. 609-621.
- Snellen, D. T. Arentze, A. Borgers, H. Timmermans. 2001. Impact of Urban Setting on Activity-Travel Patterns: Comparison of Performance Indicators with Quasi-Experimental Design Data. *Transportation Research Record 1780*, pp. 1-8.
- Song, Y. and G-J Knaap. 2004. Internally Connected, No Commercial, With a Touch of Open Space: The Neighborhoods of New Homes in the Portland Metropolitan Area. Unpublished paper provided to the author.
- Southworth, M. and P.M. Owens. 1993. The Evolving Metropolis: Studies of Community, Neighborhood, and Street Form at the Urban Edge. *Journal of the American Planning Association*, Vol. 59, No. 3, Summer, pp. 271-287.
- Sterman, J. 1999. *Business Dynamics: Systems Thinking and Modeling for a Complex World*. Draft manuscript Version 3.1, Massachusetts Institute of Technology, Sloan School of Management, August.
- Srinivasan, S. 2000. *Linking Land Use and Transportation: Measuring the Impact of Neighborhood-scale Spatial Patterns on Travel Behavior*. Submitted to the Department of Urban Studies and Planning in Partial Fulfillment of the Requirements for the degree of Doctor of Philosophy in Urban Studies and Planning, Massachusetts Institute of Technology, Cambridge MA.
- Srinivasan, S. 2001. Quantifying Spatial Characteristics for Travel Behavior Models. *Transportation Research Record No. 1777*, pp. 1-15.
- Srinivasan, S. 2002. Quantifying Spatial Characteristics of Cities. *Urban Studies*, Vol. 39, No. 11, pp. 2005–2028.
- Srinivasan, S. and J. Ferreira. 2002. Travel behavior at the household level: understanding linkages with residential choice. *Transportation Research Part D*, Vol. 7, pp. 225-242.
- Srour, I.M., K.M. Kockelman, T.P. Dunn. 2002. Accessibility Indices: Connection to Residential Land Prices and Location Choices. *Transportation Research Record 1805*, pp. 25-34.

Statistics New Zealand. 2003. *Consumer expenditure 1990-2001*. Last Accessed 19 May 2005 at: <http://www.stats.govt.nz/products-and-services/Articles/cons-exp-1990-2001.htm?print=Y>.

Strambi, O. and K.-A. van de Bilt. 2003. Untangling Factors Behind Temporal Evolution of Mobility: Case of São Paulo, Brazil. *Transportation Research Record 1807*, pp. 137-144.

Surface Transportation Policy Project (STPP). 2005. *Driven to Spend*. Center for Neighborhood Technology and Surface Transportation Policy Project. June.

Sussman, J. 1999. The New Transportation Faculty: The Evolution to Engineering Systems. *Transportation Quarterly*, Summer.

Sussman, J. and R. Dodder. 2002. The Concept of a “CLIOS Analysis Illustrated by the Mexico City Case. *Proceedings of the ESD Internal Symposium*, Massachusetts Institute of Technology, Engineering Systems Division, Cambridge, MA, 29-30 May.

Swenson, C.J. and F.C. Dock. 2003. Urban Design, Transportation, Environment and Urban Growth: Transit-Supportive Urban Design Impacts on Suburban Land Use and Transportation Planning. Report #11 in Series *Transportation and Regional Growth Study*, University of Minnesota, Center for Transportation Studies, Minneapolis, MN, March.

Talen, E. 2003. Measuring Urbanism: Issues in Smart Growth Research. *Journal of Urban Design*, Vol. 8, No. 3, October, pp. 195-215.

Talvitie, A. 1999. Performance indicators for the road sector. *Transportation*, Vol. 26, pp. 5–30.

Tanimura, M. 2004. “Urban Public Spheres” as Arenas for Composing More “Inclusive Development.” Presented at the Conference *Sustainability and Urban Growth in Developing Countries*, organized by the Institute for Spatial and Landscape Planning, Swiss Federal Institute of Technology, Monte Verita, Ascona, Switzerland, 2 November.

Todd, T.R. 1960. Forecasts of Population, Motor-Vehicle Registrations, Travel, and Fuel Consumption. *Public Roads*, Vol. 30, No. 12, pp. 261-282.

Train, K. 1986. *Qualitative Choice Analysis: Theory, Econometrics, and an Application to Automobile Demand*. MIT Press, Cambridge, MA.

Transit Cooperative Research Program (TCRP). 2003. Land Use and Site Design. Chapter 15 in *Traveler Response to Transportation System Changes*. TCRP Report 95, Transportation Research Board, Washington, DC.

Transport Canada. 1998. *Transportation in Canada 1998*. Transport Canada Policy Group. Accessed 19 May 2005 at:  
<http://www.tc.gc.ca/pol/en/Report/anre1998/TC9800AE.HTM>.

Transportation Research Board. 2002. *Surface Transportation Environmental Research: A Long-Term Strategy*. Special Report 268. National Academy of Sciences, Washington, DC.

van Diepen, A. and H. Voogd. 2001. Sustainability and planning: does urban form matter? *International Journal of Sustainable Development*, Vol. 4, No. 1, pp. 59-74.

United Kingdom Commission for Integrated Transport (UK CFIT). 2004. A Review of Transport Appraisal: Advice from the Commission for Integrated Transport. 4 October, Last accessed 18 May, 2005 at: <http://www.cfit.gov.uk/reports/rta/pdf/rta.pdf>.

United Nations Development Programme (UNDP). 2001. *Human Development Report: Making new technologies work for human development*. Oxford University Press, NY.

United Nations Development Programme (UNDP). 2004. *Human Development Report: Cultural Liberty in Today's Diverse World*.

United Nations Division for Sustainable Development (UN DSD). 2004. Web-site: <http://www.un.org/esa/sustdev/natlinfo/indicators/isd.htm> (last accessed 9 April, 2004).

United Nations Division for Sustainable Development (UN DSD). 1992. *Agenda 21*. UN Department of Economic and Social Affairs. Available at:  
<http://www.un.org/esa/sustdev/documents/agenda21/english/agenda21toc.htm> (last accessed 15 May, 2005).

United Nations (UN). 2004. World Population Prospects: The 2004 Revision and World Urbanization Prospects: The 2003 Revision. Population Division of the Department of Economic and Social Affairs of the United Nations Secretariat, <http://esa.un.org/unpp> (last accessed 12 May 2005).

United Nations (UN). 2001. *World Urbanization Prospects*. United Nations Population Division.

UN HABITAT. 2001. *Global Report on Human Settlements 2001. Statistical Annexes: Annex A*. Last Accessed 28 May, 2005 at:  
<http://www.unhabitat.org/habrdd/statannexes.htm>

U.S. Census Bureau. 2004. Gini Ratios for Families, by Race and Hispanic Origin of Householder: 1947 to 2001. Last revised 8 July 2004;  
(<http://www.census.gov/hhes/income/histinc/f04.html>).

- U.S. Census Bureau. 2005. Median Family Income by State: 1959, 1969, 1979, 1989, and 1999. Last revised 15 April 2005; (<http://www.census.gov/hhes/income/histinc/f04.html>).
- U.S. EPA. 2001. Project XL Progress Report: Atlantic Steel Redevelopment. U.S. Environmental Protection Agency, Office of the Administrator, EPA 100-R-00-026, Washington, DC, January, last accessed 11 August, 2004 at: <http://www.epa.gov/projectxl/atlantic/index.htm>).
- U.S. EPA. 2002. *Smart Growth Index: A Sketch Tool for Community Planning Version 2.0*. Prepared for the U.S. Environmental Protection Agency by Criterion Planners/Engineers, Inc., November.
- U.S. EPA. 2004. *Characteristics and Performance of Regional Transportation Systems*. United States Environmental Protection Agency, Development, Community, and Environment Division, Washington, DC, January.
- U.S. FHWA. 2002. *2002 Status of the Nation's Highways, Bridges, and Transit: Conditions & Performance*. Federal Highway Administration, U.S. Department of Transportation, Washington, DC.
- U.S. Geological Survey (USGS). 2005. 3 Arc Second Shuttle Radar Topography Mission Data. Downloaded from: <http://seamless.usgs.gov/>.
- Universidad de Chile. 2002. Estudio Repoblamiento e Intensificación del Uso del Suelo en el Anillo Central Metropolitano: Informe Final. Study prepared for the World Bank and United Nations Development Program Global Environment Facility, Santiago.
- University of Texas at Austin Statistical Services (UT-Austin). 1995. Factor Analysis Using SAS PROC FACTOR, Usage Note: Stat-53, 26 June, (<http://www.utexas.edu/cc/docs/stat53.html>).
- Urbe Consultores. 1995. *Estudio de Demanda: Valle de Santa Elena*. Santiago, April.
- Van Ardsol, M.D., S.F. Camilleri, C.F. Schmid. 1958. The Generality of Urban Social Area Indexes. *American Sociological Review*, Vol. 23, No. 3, June, pp. 277-284.
- Vasconcellos, E. 1995. Urban Transportation in Latin America: Analyzing Current Challenges. Occasional Paper Series, Latin American Studies Program, Cornell University, Ithaca, NY.
- Vasconcellos, E. 1997. The making of the middle class city: transportation policy in São Paulo. *Environment and Planning A*, vol. 29, no. 2, pp. 293-310.
- Vilhelmson, B. 1999. Daily mobility and the use of time for different activities. The case of Sweden. *GeoJournal* Vol. 48, No. 3, pp. 177-185.

Villa, M and J. Rodríguez. 1996. Demographic trends in Latin America's metropolises, 1950-1990. In *The mega-city in Latin America* (A. Gilbert, Ed.). United Nations University Press, Tokyo.

Last Accessed 28 May 2005 at:

<http://www.unu.edu/unupress/unupbooks/uu23me/uu23me00.htm#Contents>

Wachs, M. 1998. The Functions of Models and Analysis in the Policy Process. In *Transportation Models in the Policy-Making Process: Uses, Misuses, and Lessons for the Future*. Proceedings from a symposium on the problems of transportation analysis and modeling in the world of politics, Asilomar Conference Center Pacific Grove, California, March 4-6.

Wachs, M. and G. Kumagai. 1973. Physical Accessibility as a Social Indicator. *Socio-Econ. Plan. Sci.*, Vol. 7, pp. 437-456.

Wackernagel, M. 1998. The Ecological Footprint of Santiago de Chile. *Local Environment*, Vol. 3, No. 1, pp. 5-25.

Wackernagel, M. and W. Rees. 1996. *Our Ecological Footprint: Reducing Human Impact on the Earth*. New Society Publishers, Gabriola Island, BC Canada.

Walters, G., R. Ewing, W. Schroerer. 2000. Adjusting Computer Modeling Tools to Capture Effects of "Smart Growth." *Transportation Research Record 1722*, pp. 17-26.

Weaver, R. 1965. Planned Communities. *Highway Research Record Number 97*, pp. 1-6.

Webster, C. 2003. The Nature of the Neighborhood. *Urban Studies*, Vol. 40, No. 13, pp. 2591-2612.

Weisbrod, G., S. Lerman, M. Ben-Akiva. 1980. "Tradeoffs in residential location decisions: Transportation versus other factors," *Transport Policy and Decision Making*, Vol. 1, pp. 13-26.

Weisel, W.M. and J.L. Schofer. 1980. The Effects of Nucleated Urban Growth Patterns on Transportation Energy Consumption. Prepared for Research and Special Programs Administration, U.S. Department of Transportation, Washington, DC, August. Last accessed 22 May 2005 at: <http://ntl.bts.gov/DOCS/371NUG.html>.

Weng, Z. and S. Yang. 2003. An approach to evaluation of sustainability for Guangzhou's urban ecosystem. *International Journal of Sustainable Development and World Ecology*, Vol. 10, No. 1, March, pp. 69-81.

Wheeler, S.M. 2000. Planning for Metropolitan Sustainability. *Journal of Planning Education and Research*, Vol. 20, pp. 133-145.

- Williams, H.C.W.L. 1976. Travel demand models, duality relations and user benefit analysis. *Journal of Regional Science*, vol. 16, pp 147-166.
- Wood, G. 2003. Modelling the ecological footprint of green travel plans using GIS and network analysis: from metaphor to management tool? *Environment and Planning B: Planning and Design*, volume 30, pp. 523-540.
- World Bank. 1996. *Sustainable Transport: Priorities for Policy Reform*. Washington, DC.
- World Bank. 2002. *Cities on the Move: A World Bank Urban Transport Strategy Review*. Washington, DC.
- World Bank. 2003a. Chile: Sustainable Transport and Air Quality for Santiago. Project Concept Document for Global Environment Facility (GEF) Grant. Washington, DC, 31 March.
- World Bank. 2003b. *World Development Indicators 2003*. Washington, DC.
- World Bank. 2004. Chile Data Profile. Accessed on 22 April at: <http://www.worldbank.org/data/countrydata/countrydata.html>.
- World Bank. 2005. *Human Development Indicators*. Data queries performed 28 May, 2005 at: <http://devdata.worldbank.org/data-query/>.
- World Business Council for Sustainable Development (WBCSD). 2001. *Mobility 2001: World Mobility at the End of the Twentieth Century and its Sustainability*. Prepared by the Massachusetts Institute of Technology and Charles River Associates for the WBCSD Sustainable Mobility Working Group.
- World Business Council for Sustainable Development (WBCSD). 2004. *Mobility 2030: Meeting the Challenges to Sustainability*. WBCSD Sustainable Mobility Project, Geneva, July.
- WCED, 1987. *Our Common Future*. The Report of the World Commission on Environment and Development. Oxford University Press, New York, NY.
- Wyly, E. 2001. Principal Components and Factor Analysis. Background paper for Graduate Seminar *Quantitative Geographical Analysis* taught at Rutgers University, available at: <http://www.geog.ubc.ca/~ewyly/Teaching>. (last accessed 17 January 2005).
- Wyly, E.K. 1999. Continuity and change in the restless urban landscape. *Economic Geography*, Vol. 75, No. 4, October, pp. 309-338.
- Yevdokimov, Y. 2002. Sustainable Transportation System: A System Dynamics Approach. Working paper. Department of Economics, University of New Brunswick,

Canada, Accessed on 8 April 2004 at:

<http://v5o5jotqkgfu3btr91t7w5fhzedjaoaz8igl.unbf.ca/~yuri/PET2002.pdf>

Yevdokimov, Y. 2004. Sustainable Transportation in Canada. Draft paper. Departments of Economics and Civil Engineering, University of New Brunswick, Canada.

Zegras, C. 1997. Costos Estimados de Accidentes de Tránsito en Santiago de Chile, 1994. In *Actas del VIII Congreso Chileno de Transporte* (Gálvez, T., M. Munizaga, Eds.). Santiago, November, pp. 223-234.

Zegras, C. 1998a. The costs of transportation in Santiago de Chile: analysis and policy implications. *Transport Policy*, Vol. 5, Winter, pp. 9-21.

Zegras, C. 1998b. Transporte Urbano e Impactos Locales: Economía, Contaminación, Bienestar. *Transporte Urbano y Ambiente: Bases para una Política Ambiental en el Transporte Urbano*. Consejo Nacional del Ambiente, Lima, Perú, October.

Zegras, C. 2003. Financing Transport Infrastructure in Developing Country Cities: Evaluation of and Lessons from Nascent Use of Impact Fees in Santiago de Chile. *Transportation Research Record 1839*, pp. 81-88.

Zegras, C. 2004. The Influence of Land Use on Travel Behavior in Santiago, Chile. *Transportation Research Record 1898: Travel Demand and Land Use 2004*, pp. 175-182.

Zegras, C. and M. Birk. 1994. Moving Towards Integrated Transport Planning: Energy, Environment, and Mobility in Four Asian Cities. *Transportation Research Record No. 1441*, pp. 84-92.

Zegras, C. and R. Gakenheimer. 2000. Urban Growth Management for Mobility: The Case of the Santiago, Chile Metropolitan Region. Working Paper for the Lincoln Institute of Land Policy and the MIT Cooperative Mobility Program, Cambridge.

Zegras, C. and T. Litman. 1997. *An Analysis of the Full Costs and Impacts of Transportation in Santiago de Chile*. International Institute for Energy Conservation, Washington, DC.

Zegras, C., I. Poduje, W. Foutz, E. Ben-Joseph, O. Figueroa. 2004. Indicators for Sustainable Urban Development. Chapter 7 in *From Understanding to Action: Sustainable Urban Development in Medium-Sized Cities in Africa and Latin America* (M. Keiner, C. Zegras, W. Schmid, D. Salmerón, Eds.), Springer, Dordrecht, the Netherlands.

Zegras, C., J. Sussman, C. Conklin. 2004. Scenario Planning: A Proposed Approach for Strategic Regional Transportation Planning. *Journal of Urban Planning and Development*, Vol. 130, No. 1, American Society of Civil Engineers, pp. 2-13.

Zehner, R.B. 1977. *Access, Travel, and Transportation in New Communities*. Cambridge, MA, Ballinger.

Zhang, M. 2002. Conditions and Effectiveness of Land Use as a Mobility Tool. Submitted to the Department of Urban Studies and Planning in Partial Fulfillment of the Requirements for the degree of Doctor of Philosophy in Urban Studies and Planning, Massachusetts Institute of Technology, Cambridge MA.

Zhang, M. 2004. The Role of Land Use in Travel Mode Choice: Evidence from Boston and Hong Kong. *Journal of the American Planning Association*, Vol. 70, No. 3, Summer, pp. 344-360.

Zhang, M. and N. Kukadia. 2005. Metrics of Urban Form and the Modifiable Areal Unit Problem. Paper presented at the 84<sup>th</sup> Annual Meeting of the Transportation Research Board, Washington, DC, 9-13 January.

Zietsman, J. and L.R. Rilett. 2002. Sustainable Transportation: Conceptualization and Performance Measures. Report 167403, Texas Transportation Institute, The Texas A&M University System, College Station, Texas, March.

Zietsman, J., L. R. Rilett, S.-J. Kim. 2003. Sustainable Transportation Performance Measures for Developing Communities. Report 167128, Texas Transportation Institute Texas A&M University System, College Station, Texas.