Job Accessibility in the San Juan Metropolitan Region (SJMR)  
-- Maximizing the Benefits of Tren Urbano

by

Ming Zhang

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

MASTER OF SCIENCE IN TRANSPORTATION

At the  
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
June 1999

© 1999 Massachusetts Institute of Technology  
All rights reserved

Signature of Author ____________________________  
Department of Urban Studies and Planning  
May 20, 1999

Certified by ____________________________  
Qing Shen  
Assistant Professor  
Department of Urban Studies and Planning  
Thesis Co-Supervisor

Certified by ____________________________  
Joseph M. Sussman  
JR East Professor  
Professor of Civil and Environmental Engineering  
Thesis Co-Supervisor

Accepted by ____________________________  
Paul Smoke  
Associate Professor of Urban Studies and Planning  
Chairman, Department of Urban Studies and Planning Graduate Studies
Job Accessibility in the San Juan Metropolitan Region (SJMR) -- Maximizing the Benefits of Tren Urbano

by

Ming Zhang

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

Abstract
Public transportation investment is made because of its potential benefits to the society. Properly identifying and measuring these benefits has been the central concern in rail transit decision making. In this research, we focus on the social dimension of rail transit benefits through the Tren Urbano case study. The objectives are: (1) to characterize the social benefits of public transportation, especially rail transit systems, in terms of job accessibility provision; (2) to analyze the distributional effects of the Tren Urbano benefits among geographical locations and social groups in the SJMR; and (3) to examine the effects of supplementary transportation and land use strategies in further enhancing job accessibility in the region.

A comparative study method in combining with simple simulations is used for this research. Comparisons of accessibility levels are made between Tren Urbano-Build and No-Build scenarios in 2010, and between 2010 Cases and 1990 Base Case. Policy scenarios are simulated under several assumptions of transportation and land use policies. GIS is utilized to link and process geographical and statistical information, and to visualize the intermediate and final results of analyses.

The study results suggest that, through mobility provision, Tren Urbano would contribute to improve job accessibility in the SJMR. All social groups would be better off from the investment comparing to the No-Build alternative. The study also raises concerns that, without additional transportation and land use policies to support Tren Urbano, the benefits of the investment would be quite limited, both geographically and socially. There are both needs and opportunities for policy makers to intervene. From transportation planners' perspective, there are untapped potentials for further improving Publico services. From land use planners' perspective, there are nearly 1200 acres of vacant developable land near Tren Urbano (Phase I) stations. Based on the scenario analysis results, policy recommendations are made aiming to maximize the social and economic returns of Tren Urbano.

Thesis Co-Supervisor: Qing Shen
Title: Assistant Professor of Urban Studies and Planning

Thesis Co-Supervisor: Joseph M. Sussman
Title: JR East Professor
Professor of Civil and Environmental Engineering
Acknowledgements

Many thanks to Professor Qing Shen and Professor Joseph Sussman for their devoting significant amount of time in guiding, advising, and pushing me toward the directions of more efficient intellectual learning and academic productiveness. The direct results from which are two publications drawn from the contents of this research, whereas the experience of working with them will be a lifetime benefit to me.

Particular thanks are due to Professor Nigel Wilson and Mr. Fred Salvucci for their faith in my ability to conduct this project and providing both financial and intellectual support to me through the Tren Urbano Project at MIT. Their comments on and feedback to my work have always been insightful.

Dr. Antonio Gonzalez and others from the University of Puerto Rico (UPR) have provided helpful information about Tren Urbano, San Juan, and Puerto Rico during the MIT_UPR Courses. The trip to the beautiful island (Puerto Rico) allowed me to gain first-hand experience about Tren Urbano-related issues, and to enjoy the heavenly places like El Yunque. Many thanks to our hosts in San Juan and Mayaguez.

Ms. Ledia Mercado and Ms. Marisol Rodriguez Rivera at the Tren Urbano Office in San Juan, and Ms. Malinda Foy and Mr. William Craven at CambridgeSystematics, Inc. in Cambridge, MA, provided most of data needed for this research.

The residence of my former colleague and long time friend, Zejun Gong, was where I sought relaxation and inspiration. Whenever I was stuck with my work, I went and chatted with him and had never returned with empty hands. Thanks to him and his wife, Wei Liu. Thanks are also due to my colleagues in the research team of the Tren Urbano Project for their help and suggestions throughout my work.

I am deeply indebted to my wife, Ping Wang, to our son, Yi, and to our parents for their love, care, encouragement and continuing support.
# Table of Contents

Title Page.......................................................................................................................... 1  
Abstract............................................................................................................................... 3  
Acknowledgements............................................................................................................ 5  
Table of Contents............................................................................................................... 7  
List of Figures .................................................................................................................... 10  
List of Tables .................................................................................................................... 11  

**Chapter 1 Introduction** ............................................................................................... 13  
1.1 The North American “Rail Renaissance”................................................................. 13  
1.2 Expectations from Rail Transit Systems................................................................. 13  
1.3 The Ongoing Debate on Rail Transit Investment.................................................. 18  
1.4 Motivations and Objectives of the Thesis............................................................ 18  
1.5 Research Questions................................................................................................. 20  
1.6 Outline of the Thesis............................................................................................... 20  

**Chapter 2 Transit Benefit Analysis** ........................................................................... 23  
2.1 Characterizing Transit Benefits............................................................................. 23  
2.1.1 The Nature of Transit Benefits ....................................................................... 23  
2.1.2 The Benefit Tree.............................................................................................. 24  
2.1.3 Issues in Transit Benefit Analysis...................................................................... 27  
2.1.4 Limitation of the Benefit Tree.......................................................................... 28  
2.2 Empirical Findings of Transit Benefit Analysis.................................................... 28  
2.2.1 The Land Use/Urban Economic Development Benefits................................. 28  
2.2.2 The environmental Benefits............................................................................... 33  
2.2.3 The Social Benefits.......................................................................................... 34  
2.2.4 The Direct Employment Benefits...................................................................... 34  
2.3 Summary and Findings............................................................................................ 34  

**Chapter 3 Accessibility Measures and Applications** ............................................. 35  
3.1 Definitions of Accessibility...................................................................................... 35  
3.1.1 Conceptualizing Accessibility.......................................................................... 35  
3.1.2 Distinguishing between Mobility and Accessibility................................. 37  
3.1.3 An Example....................................................................................................... 39  
3.2 Measurements of Accessibility.............................................................................. 40  
3.2.1 Performance-Based Measures......................................................................... 42  
3.2.2 Potential-Based Measures................................................................................ 43  
3.2.3 Preference-Based Measures.............................................................................. 44  
3.2.4 Selecting an Appropriate Accessibility Measure............................................ 45  
3.3 Applications of Accessibility................................................................................... 46  
3.3.1 Land use-Transportation Modeling................................................................. 46  
3.3.2 Characterization of Urban Environment......................................................... 46  
3.3.3 Project Evaluation and Policy Analysis............................................................ 47
3.4 Summary and Findings.......................................................... 49

Chapter 4 Job Accessibility in the SJMR.................................................. 51
  4.1 Methodology................................................................. 52
    4.1.1 Selecting an Accessibility Measure.......................... 52
    4.1.2 Data Sets........................................................... 53
    4.1.3 The Tools............................................................. 54
  4.2 Characterization of the Spatial Structure of the SJMR .............. 54
    4.2.1 Population and Employment Distributions.................... 54
    4.2.2 Road Network and Public Transportation...................... 64
  4.3 Job Accessibility in the SJMR: the 1990 Base Case................. 66
    4.3.1 Regional Job Accessibility Patterns.......................... 66
    4.3.2 Accessibility Patterns with Different Transportation Modes... 66
    4.3.3 TAZ Accessibility Scores by Income Classification.......... 67
  4.4 Job Accessibility in the SJMR: the 2010 Tren Urbano Build and No-Build Cases..... 79
  4.5 Summary and Findings.................................................. 82
    4.5.1 The 1990 Base Case Study..................................... 82
    4.5.2 The 2010 Tren Urbano-Build and No-Build Case Studies..... 83

Chapter 5 Policy Scenario Analysis and Policy Recommendations........... 85
  5.1 Mobility Approach to Improving Job Accessibility.................. 85
    5.1.1 Transportation Policy Scenario Design........................ 85
    5.1.2 Effects of Mobility Policy on Job Accessibility............. 87
  5.2 Land Use Approach to Improving Job Accessibility................ 88
    5.2.1 Defining Transit Land Use Impact Zone.......................... 90
    5.2.2 Evaluating Station Area Walking Environment................. 91
    5.2.3 Land Use Policy Scenario Design.............................. 95
    5.2.4 Effects of Land Use Policy on Job Accessibility.......... 98
  5.3 Implications and Policy Recommendations.......................... 101
    5.3.2 Policy Recommendations........................................ 101
    5.3.3 Implications for the Phasing Strategies of
    Tren Urbano Extensions.............................................. 104
  5.4 Summary................................................................. 105

Chapter 6 Conclusions...................................................................... 107
  6.1 Implications of the Research Findings.................................. 107
  6.2 Challenges to and Opportunities in San Juan........................ 109
  6.3 Contributions of This Research....................................... 110
  6.4 Directions for Future Studies........................................ 111

End Note: Transit Impact Zone and Calculation of Walkability Index (WI)... 113
References Cited................................................................................................. 115

Appendix A: Technical Documentation................................................................. 121
  A1: ArcInfo AML Codes for Data Processing..................................................... 121
  A2: C Codes for Accessibility Calculation....................................................... 124

Appendix B: Data Inventory.................................................................................. 142
# List of Figures

<table>
<thead>
<tr>
<th>FIGURE</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>The Tren Urbano System</td>
<td>15</td>
</tr>
<tr>
<td>2.1</td>
<td>Transit Benefit Tree</td>
<td>25</td>
</tr>
<tr>
<td>3.1</td>
<td>Mobility vs. Accessibility: An Example</td>
<td>39</td>
</tr>
<tr>
<td>3.2</td>
<td>A Typology of Accessibility Measures</td>
<td>41</td>
</tr>
<tr>
<td>3.3</td>
<td>The Space-Time Prism</td>
<td>42</td>
</tr>
<tr>
<td>4.1</td>
<td>The Geography of SJMR</td>
<td>55</td>
</tr>
<tr>
<td>4.2</td>
<td>Spatial Distribution of Population in SJMR</td>
<td>57</td>
</tr>
<tr>
<td>4.3</td>
<td>Spatial Distribution of Jobs in SJMR</td>
<td>59</td>
</tr>
<tr>
<td>4.4</td>
<td>Spatial Distribution of Income Groups in SJMR</td>
<td>61</td>
</tr>
<tr>
<td>4.5</td>
<td>Highway and Street Pattern of the SJMR (1990)</td>
<td>65</td>
</tr>
<tr>
<td>4.6</td>
<td>Bus (AMA) Service Coverage in the SJMR (1990)</td>
<td>65</td>
</tr>
<tr>
<td>4.7</td>
<td>Job Accessibility Pattern in the SJMR (Auto Mode)</td>
<td>69</td>
</tr>
<tr>
<td>4.8</td>
<td>Job Accessibility Pattern in the SJMR (Publico Mode)</td>
<td>71</td>
</tr>
<tr>
<td>4.9</td>
<td>Job Accessibility Pattern in the SJMR (Bus Mode)</td>
<td>73</td>
</tr>
<tr>
<td>4.10</td>
<td>Job Accessibility Pattern in the SJMR (All Transit Mode): 2010 Tren Urbano Build Case</td>
<td>75</td>
</tr>
<tr>
<td>4.11</td>
<td>Job Accessibility Change in the SJMR (All Transit Mode): The 1990 Base vs. 2010 Tren Urbano Build Case</td>
<td>77</td>
</tr>
<tr>
<td>5.1</td>
<td>Evaluation of Station Area Walking Environment: Example of Tren Urbano in the SJMR</td>
<td>93</td>
</tr>
<tr>
<td>6.1</td>
<td>Transit Impact Zone and Calculation of Walkability Index</td>
<td>114</td>
</tr>
</tbody>
</table>
List of Tables

TABLE 1.1 Rail Transit Systems in the U.S. and Canadian Cities................. 14
TABLE 2.1 Transit’s Share of Commute Trips in Four Metropolitan
Regions, CA..........................................................33
TABLE 4.1 Population and Employment in Municipalities of SJMR (1990)..... 63
TABLE 4.2 1990 Base Case:
Population-Weighted Accessibility Scores and Indices..................68
TABLE 4.3 2010 Cases:
Population-Weighted Accessibility Scores and Indices...............80
TABLE 5.1 Effects of Transit Service Improvement on Job Accessibility.....89
TABLE 5.2 Station Area Characteristics by TAZ Groups,
Tren Urbano Phase I ................................................. 97
TABLE 5.3 Effects of Increasing Development Intensity on
Job Accessibility in Tren Urbano Phase I Station Areas.............. 100
TABLE 5.4 Effects of Land Use Change on Job Accessibility in
Tren Urbano Phase I Station Areas.................................. 102
TABLE 5.5 General Characteristics of Tren Urbano Station Areas by Phase...103
Chapter 1

Introduction

1.1 The North American “Rail Renaissance”

“America is in the midst of a rail renaissance” (Bernick and Cervero 1997:49). In the past decades, many U.S. and Canadian cities have started building new rail transit systems or extending existing ones (Table 1.1).

Since the late 1970s, both rapid growing cities such as Miami, Atlanta, Denver, and San Diego, and declining cities such as Baltimore, Buffalo, Detroit, and Pittsburgh have planned and built rail service. In older cities like New York, Boston, Philadelphia, Toronto, Cleveland, and Chicago, rail lines have been extended into outer suburban areas. By the mid-1990s rail service was available, under construction, or being planned for over two dozen metropolitan areas in North America. Other major urban regions, including Seattle, Salt Lake City, Tampa, and Raleigh-Durham, have undertaken extensive planning for rail transit (Porter 1998). These systems, in one specific type or in combination of light rail, heavy rail, or commuter train, have formed or are expected to form the backbones of metropolitan-wide public transportation networks.

Tren Urbano, the subject of the case study in this thesis, is among those being constructed in the current rail renaissance. It is a heavy-rail rapid transit system located in the central area of San Juan Metropolitan Region (SJMR) of Puerto Rico. The Phase I of Tren Urban is 12 miles long and features 16 stations serving major employment and residential centers of SJMR. The $1.25 billion project began in 1996 and is expected to start operating in 2001 and complete by 2010. Three plans for extension of the Phase I have also been identified (Figure 1.1).

1.2 Expectations from Rail Transit Systems

It is hoped that rail systems not only provide cities with quality public transportation services but also offer opportunities to promote alternative development strategies to automobile-oriented development. The public concerns over excess automobile usage can
<table>
<thead>
<tr>
<th>REGION</th>
<th>Year Opened</th>
<th>In Operation</th>
<th>Extension/New Plan</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chicago</td>
<td>1892</td>
<td>HRT, CR</td>
<td>LRT, HRT, CR</td>
</tr>
<tr>
<td>Boston</td>
<td>1897</td>
<td>HRT, CR</td>
<td>CR</td>
</tr>
<tr>
<td>New York</td>
<td>1904</td>
<td>HRT, CR</td>
<td>LRT, HRT, CR</td>
</tr>
<tr>
<td>Philadelphia</td>
<td>1905</td>
<td>HRT, CR</td>
<td>CR</td>
</tr>
<tr>
<td>Toronto</td>
<td>1954</td>
<td>HRT, CR</td>
<td>LRT</td>
</tr>
<tr>
<td>Cleveland</td>
<td>1955</td>
<td>LRT, HRT</td>
<td>LRT, HRT, CR</td>
</tr>
<tr>
<td>New Jersey</td>
<td>1969</td>
<td>HRT, CR</td>
<td>LRT, CR</td>
</tr>
<tr>
<td>Montreal</td>
<td>Pre-1970</td>
<td>HRT, CR</td>
<td></td>
</tr>
<tr>
<td>San Francisco</td>
<td>1974</td>
<td>HRT</td>
<td>LRT, HRT, CR</td>
</tr>
<tr>
<td>Washington, DC</td>
<td>1976</td>
<td>HRT</td>
<td>HRT</td>
</tr>
<tr>
<td>Edmonton</td>
<td>1978</td>
<td>LRT</td>
<td>LRT</td>
</tr>
<tr>
<td>Atlanta</td>
<td>1979</td>
<td>HRT</td>
<td>HRT, CR</td>
</tr>
<tr>
<td>San Diego</td>
<td>1981</td>
<td>LRT</td>
<td>LRT, CR</td>
</tr>
<tr>
<td>Baltimore</td>
<td>1983</td>
<td>LRT, HRT</td>
<td>LRT, HRT, CR</td>
</tr>
<tr>
<td>Miami</td>
<td>1984</td>
<td>HRT</td>
<td>HRT</td>
</tr>
<tr>
<td>Buffalo</td>
<td>1985</td>
<td>LRT</td>
<td>LRT</td>
</tr>
<tr>
<td>Portland</td>
<td>1986</td>
<td>LRT</td>
<td>LRT</td>
</tr>
<tr>
<td>Vancouver</td>
<td>1986</td>
<td>HRT</td>
<td>CR</td>
</tr>
<tr>
<td>Sacramento</td>
<td>1987</td>
<td>LRT</td>
<td>LRT</td>
</tr>
<tr>
<td>San Jose</td>
<td>1987</td>
<td>LRT</td>
<td>LRT</td>
</tr>
<tr>
<td>Pittsburgh</td>
<td>1988</td>
<td>LRT</td>
<td>LRT</td>
</tr>
<tr>
<td>Los Angeles</td>
<td>1990</td>
<td>LRT, HRT, CR</td>
<td>LRT, HRT, CR</td>
</tr>
<tr>
<td>St. Louis</td>
<td>1993</td>
<td>LRT</td>
<td>LRT, CR</td>
</tr>
<tr>
<td>Denver</td>
<td>1994</td>
<td>LRT</td>
<td>LRT, CR</td>
</tr>
<tr>
<td>Memphis</td>
<td>1995</td>
<td>LRT</td>
<td>LRT</td>
</tr>
<tr>
<td>Dallas</td>
<td>1996</td>
<td>LRT</td>
<td>LRT, CR</td>
</tr>
<tr>
<td>Hartford</td>
<td></td>
<td></td>
<td>CR</td>
</tr>
<tr>
<td>Kansas City</td>
<td></td>
<td></td>
<td>LRT</td>
</tr>
<tr>
<td>Salt Lake City</td>
<td></td>
<td></td>
<td>LRT</td>
</tr>
<tr>
<td>San Juan</td>
<td></td>
<td></td>
<td>HRT</td>
</tr>
<tr>
<td>Seattle</td>
<td></td>
<td></td>
<td>LRT, CR</td>
</tr>
</tbody>
</table>

Sources: Bernick and Cervero 1997 and Porter 1998

Note:
- LRT: Light Rail Transit
- HRT: Heavy Rail Transit
- CR: Commuter Rail
FIGURE 1.1: The TrenUrbano System in the SJMR

LEGEND:
- Tren Urbano Phases
  - ● Phase 1 (under construction)
  - ● Phase 2 (proposed)
  - ▲ Phase 3 (proposed)
  - ■ Phase 4 (proposed)
- SJMR Region
- Municipality Boundary
- Street Networks
be summarized in the following five aspects (Bernick and Cervero 1997). The first is traffic congestion. Rapid increases in automobile travel coupled with limited road expansion have brought unprecedented levels of traffic congestion in recent years, especially in the suburbs. The social costs of traffic congestion, including wasted time and energy, added pollution, increased accidents, and a reduction in economic productivity, are significant.

The second is environmental concerns. Despite much cleaner the newer model automobiles, air quality in many urban areas has improved little, and in some places it has deteriorated. This is because the contribution of new technology in improving air quality has largely been offset by the growth in vehicle population and miles driven. Automobiles are also major contributors to the production of greenhouse gases.

The third is the concern of energy conservation. Since 1975, transportation demands for oil have exceeded U.S. domestic production, making the nation dependent on foreign sources for imports (40 percent of consumption in 1993) and therefore vulnerable to disruptions in flows.

The fourth concern is social equity. A troubling effect of an increasingly auto-dependent society is the social injustices, resulting from physically and socially isolating segments of society, to access jobs and services. Eventually, it is the entire society that will suffer the costs of continuing to isolating a significant segment of society in inner-city ghettos.

Finally, the fifth concern is the overall declining quality of life resulting from the collective costs (e.g. congestion, pollution, and sprawl) of a heavily auto-dependent society.

The renewed interest in rail transit is partly in response to these concerns. It is hoped that good quality transit services can induce modal shifts away from automobiles and thus reduce road congestion and air pollution. With quality transit systems, transit-based development strategies, that is, concentrating developments around transit stations at a relatively high density and mixture of uses in a pedestrian-friendly environment, can also be implemented (Duany and Plater-Zyberk 1991, Calthorpe 1993, Katz 1994,
Bernick and Cervero 1997). This in turn will support better transit services and ultimately alleviate the problems associated with automobile dependency.

1.3 The Ongoing Debate on Rail Transit Investment

Amid the waves of rail transit construction across North America, there is also an ongoing debate on whether or not the ultimate benefits from transit development justify the major expenditure of public funds. Despite the variety of benefits cited by transit proponents, the opponents argue that the actual effects of transit systems often do not meet those stated objectives. Claimed or perceived benefits of rail transit development are mostly based on hopes and are often overestimated and misleading (Kain 1990 and Pickrell 1990). From 1965 to 1995, the total deficit of transit systems nationwide was over $150 billion (APTA 1996 in Semmens 1997). This poor rate of return suggests that, from a purely financial standpoint, public transit is simply not a good investment (Semmens 1997).

There are also doubts about the effectiveness of land use initiatives in affecting people’s travel behavior. It has been argued that the linkage between land use and transportation is weakening in the U.S. due to decreasing real costs of travel, the existence of already well-developed transportation systems, and structural shifts to information-based economy. Therefore, land use policies may not have much effect on travel outcomes (Gordon, et al. 1991, Giuliano 1995 and Pickrell 1999). And the expected role of transit in promoting alternative development strategies would become rootless.

1.4 Motivations and Objectives of the Thesis

Motivations

Our research was motivated by the growing interests in rail transit or public transportation systems in general, by the increasing public concerns over current metropolitan development patterns, and by the continuing policy debates in the area. However, in this thesis, we do not intend to address every aspect of the debate over rail transit investment or transit-based development. Instead, we direct our attention to the measurement issues
in rail transit benefit analysis. More specifically, through the Tren Urbano case study, we focus on the social dimension of rail transit investments—improving the quality of life, the measurement of this particular aspect of transit benefits, and identification of desirable strategies or policies to maximize the social returns of rail transit development. The topic is important for at least three reasons that follow:

(1) Properly identifying and measuring the benefits of rail transit has been the central concern in rail transit investment and development. Much of the debate stems from the discrepancies between expected and actual benefits, and perceived and measured transit benefits, from the methodological approaches that measurements are conducted and from the chosen standpoints from which arguments are made. An appropriate measure should not only help better quantify the benefits, but also be able to identify possible hidden, undesirable consequences of the investment, and therefore it will better inform policy debate and decision making.

(2) The ultimate goal of transportation investments is to improve the quality of life. It is commonly perceived that rail transit contribute to maintain and improve the quality of life (Nuwirth 1990, and Cervero 1994b). However, this perceived benefit is difficult to measure. The topic of quality of life is the least articulated area in current transportation policy debates (Bernick and Cervero 1997).

(3) Better understanding the benefit measurement issues, particularly in the social dimension of transit benefits, contributes to the literature in the field. The case study of Tren Urbano also provides timely information to the local governments in the SJMR in formulating desirable supplemental policies aiming to maximize the returns of Tren Urbano investment.

Objectives

Accessibility to employment and urban services constitute an important measure of the quality of urban living and should be included as an important component of a ‘social report’ for a city or region (Wachs and Kumagai 1973). In the Tren Urbano case study
presented in this thesis, we focus on the job accessibility in the SJMR. The objectives of the research are:

- To characterize the social benefits of public transportation, especially rail transit systems, in terms of job accessibility provision and contribute to the literature combining two fields of inquiry: transit benefit analysis and accessibility measures.
- To analyze the distributional effects of the Tren Urbano benefits -- measured in terms of job accessibility enhancement -- among geographical locations and social groups in the SJMR.
- To examine the effects of supplementary transportation and land use strategies in further enhancing job accessibility in the region and identify desirable policies aiming to maximize the benefits of Tren Urbano.

1.5 Research Questions
Two sets of research questions are addressed through literature review and the Tren Urbano case study: the analytical and the policy questions.

The analytical questions are: How do transit systems create benefit to society? What characteristics they have in accessibility provision? How to define and measure job accessibility? What are the existing patterns of job accessibility in the SJMR? How will job accessibility change as a result of Tren Urbano? What are the distributional effects of the accessibility change?

The policy questions are: What land use and transportation strategies will help redistribute the benefits of rail transit toward more desirable social outcomes? What are the main factors affecting job accessibility in the SJMR? What complementary policies and strategies would help to maximize the benefits of rail transit development? What lessons can be learnt from the Tren Urbano case study on rail transit benefit analysis?

1.6 Outline of the Thesis
The thesis consists of six chapters. Chapter one explains the motivation, objectives, and research questions and outlines the structure of the thesis.
Chapter two and three review relevant literature on two subjects: rail transit benefit analysis and accessibility, respectively. They summarize the current knowledge on the role of transit, particularly rail transit, in improving the quality of life. A detailed survey of literature on accessibility helps construct an appropriate methodological framework for our case study.

Chapter four presents the case study of Tren Urbano, SJMR, applying the accessibility framework. It first explains the accessibility model, data sets, and tools used for the analysis. Next, a brief review of the regional characteristics in population and job distribution, income groups and their spatial locations, road networks, and public transportation services is provided. Finally, the results of measurement for the 1990 Base Case and the 2010 Tren Urbano-Build and No-Build cases are reported by means of thematic maps and numerical tables. Policy concerns are raised based on the findings of the case study.

In Chapter five, a number of policy alternatives from both transportation and land use perspectives are introduced in response to the concerns raised in the previous chapter. The effects of these policy alternatives on job accessibility in the SJMR are examined and discussed. At the end, several policy recommendations are made.

The thesis concludes with Chapter six, which draws implications from the case study. It also discusses the contribution of this research and finally points to the directions for future research.

The appendices contain technical documentation, including the codes of ARC Macro Language (AML) for data processing using ArcInfo GIS, major C codes for accessibility calculation and an inventory of the data sets collected for this research.
Transit Benefit Analysis

Transit benefit analysis concerns the consequences of a transit investment, assuming that the decision had been made or an alternative had been chosen. In terms of the scope of analysis, it may partly overlap with the conventional cost-benefit analysis, which is derived from economic theory. They differ in that transit benefit analysis addresses a broader range of issues in the economic, environmental, political and social dimensions of transit induced consequences.

In this chapter, we first review the literature on the characterization and measurement of transit benefits. A framework of measuring transit benefits suggested by the literature is presented and several common issues in transit benefit analysis are also discussed. Next, we review major empirical findings touching on various aspects of transit induced effects. While summarizing the current understanding of transit benefits, we also point out the limitations of the literature and suggest research gaps to be filled.

2.1 Characterizing Transit Benefits

2.1.1 The Nature of Transit Benefits

Transit is one type of transportation technologies reflecting the efforts of human being to overcoming spatial barriers. Thus, the very basic nature of transit benefit is providing access to distributed opportunities, just as in the case of automobile. What distinguishes transit from automobile is that transit provides a means of travel in mass volumes. One may expect the consequences (in aggregate) resulting from travel by transit more desirable than by automobiles (discussed in Section 1.2).

Furthermore, the spatial patterns of accessibility benefit generated by transit differ from that by auto. In the case of rail transit, the accessibility effects only exhibit through stations because, due to the operational features of transit, accessing the system itself is constrained to a limited number of station locations. Also, using the system requires
mode transfer from non-transit such as walk to transit. Consequently, there are two tiers of accessibility effects associated with transit. The first is the system accessibility effect relating to the reduced commuting costs to various locations through the system. The second is the station site accessibility effect relating to accessing the stations from surrounding areas. Both tiers of accessibility effects attract attentions from planners and invites debates.

In contrast, in the highway-automobile case, the system accessibility benefit dominates because no mode transfer is involved. Spatially, automobile-based accessibility benefits are more dispersed than transit-based because of the availability of equally accessible highway networks.

2.1.2 The Benefit Tree

Arguing that transit has unique characteristics that do not fit well with traditional methods of benefit-cost analysis, Beimborn, et al. (1993) construct a comprehensive framework—the benefit tree—for the measurement of transit benefits.

According to Beimborn, et al., transit benefits can be viewed as the consequences of transit investments that are valued by some segments of the population. These consequences range from the basic (need for bus stops, purchase of fuel) to direct effects (trips made by transit, employment of works in transit firms) to indirect effects (changes in land use, independent life styles). The benefit tree accounts for these consequences and their relationships. The tree is divided into four branches—alternative, travel, land use, and supply, where each branch categorizes one type of transit benefits. Figure 2.1 shows the first two levels of the benefit tree.

Alternative

Transit provides an alternative means of travel that may or may not actually be used by any given individual. Because transit is available, people have options to travel for unusual occurrences.
FIGURE 2.1: Transit Benefit Tree

TRANSPORT BENEFITS

Alternative

Long term mobility option
Unusual occurrences when an automobile is not available
Recreational riding
Independent living of youth, elderly and other dependents

Travel

Fewer auto trips
Transit trip making

Land Use

Efficiency of public services
Interaction among people
Land preservation

Supply

Operations involving employment and consumption of resources
Community support
Facilities

Source: Beimborn, et al. 1993, (including only the first two levels of the benefit tree)
Travel
Transit trip making occurs resulting from a shift from automobile or from the transit dependent. Transit trip-making in turn results in changes in user resources (time, cost, etc.), changes in facility needs, environmental effects and so forth.

Land Use
Transit improves accessibility of the land in the vicinity of stations, making the land more valuable, causing shifts in life styles, and affecting the efficiency of certain public services.

Supply
Transit exists as an enterprise that employs people in its operation and construction, and demand resources.

Some types of benefits can be quantified straightforwardly whereas others may only be measured in qualitative terms.

The value of having transit available as an alternative (option value) is difficult to estimate. These effects could be described in words or else measured in a general sense; i.e., overall size of service area or the population of households without automobiles served. More detailed estimates could be found from looking at the costs (or consumer surplus) of providing such advantages by means other than transit, for example, use of taxicab service in the event of an automobile breakdown.

Travel related benefits for both automobile users and transit users can be estimated through an enhanced consumer surplus technique. This technique can be used to estimate the user effects from savings in travel time, operating and packing costs, and destination choice that result if the transit system is changed. Environmental effects of travel could be measured by trip related multipliers. If the number of trips is known along with some of their characteristics (i.e., length, speed, delay, and vehicle type), then estimates can be made for energy, air pollution, and noise consequences.
Transit effects on land use can be partially measured through a consumer surplus approach if the land use modeling structure permits land use distribution to change. Other land use consequences that result from concentration are more difficult to measure. Efficiency of public services and interaction may need to be described in words. Land preservation could be found from the results of a travel demand/land use model.

The presence of transit has a variety of effects. Transit facility construction and operation employ people and consume resources. In addition, the presence of a transit system can generate local community pride and prestige. Such intangibles are difficult to quantify but may be quite significant to a community. Employment impacts can be determined through an input-output analysis or through a direct, inventory approach.

2.1.3 Issues in Transit Benefit Analysis
When the framework—the benefit tree is applied to transit benefit analysis, several issues raised by Beimborn, et al. are worth noting.

Viewpoints
Depending on the specific viewpoints, e.g. geographical, institutional, or social, the consequences of transit investment may be seen positive or negative and may vary in relative importance. Geographically, benefits of transit from a national point of view may be quite different from those perceived at the regional or local level. It may be important to local governments that employment gains occur in a particular neighborhood or political jurisdiction. From a regional point of view, employment may only shift between subareas resulting in a ‘zero sum game’. As the geographic scope of analysis increases, shifts from one area to another become internalized and may no longer be viewed as net benefits, although distributional benefits may exist. From an institutional point of view, benefits to transit agencies include only those contribute to the rate of return that can be captured by the agencies. From the social equity point of view, benefit distribution among segments of population is the major concern.
Perceived versus Measured versus Actual Benefits

Benefits occur because people perceive them and believed them to be important, regardless whether or not they can be measured explicitly. Moreover, benefits that are perceived may be much different from ones that can be measured and some are perhaps impossible to measure. For example, fairness, aesthetics, social interaction, and image are difficult to convincingly quantify in monetary terms. Naturally, perceptions do not necessarily reflect the real.

Double Counting

The issue of double counting is easy to understand but hard to avoid. For example, when energy savings, fuel tax revenues and vehicle operating cost savings are considered as categories of transit generated benefits, fuel use is counted several times. Double counting is complex and cannot be totally eliminated. The simplest way to overcome many of the problems with double counting is to not add benefits together.

2.1.4 Limitation of the Benefit Tree

The ‘cookbook’ prepared by Beimborn, et al. provides practitioners with excellent guidance to the measurement of transit benefits. The various techniques and examples for transit benefit analysis introduced are valuable sources for transit project evaluation. An obvious weakness of the ‘cookbook’ is the omission of detailed discussion on the social dimension of transit development consequences. It does not suggest operational procedures or methods measuring the effects of transit investments on the social welfare, or the quality of life of population groups.

2.2 Empirical Findings of Transit Benefit Analysis

2.2.1 The Land Use/Urban Economic Development Benefits

The land use benefits of rail transit systems exist due to the improvement in accessibility citywide and in the vicinity of stations. Identifying and measuring the expected accessibility effects have been the focus of transit benefit analysis.
A direct approach to examine the expected site accessibility benefit of transit is to look at land use changes in terms of density, intensity or types in response to the presence of transit. Studies can be conducted by doing before- vs. after- comparison using time series data or with- vs. without- comparison through simulation. It can also be done using cross-sectional data by examining the distance-decay effect of land use activities with respect to the location of stations.

Alternatively, the accessibility benefit can be identified through measuring the relationship between property values and distance to stations. According to theory of land economics, the accessibility benefit generated by transit should be capitalized into surrounding properties (Brigham 1965).

In general, three quantitative approaches have largely been used to date to examine effects of proximity to transit on property values and rents.

**Hedonic Price Models**

Hedonic Price Models employ regression analysis to attach a monetary value to different attributes of a property and its surroundings, including the proximity of the parcel to transit. Cross-sectional or time series data, or both, are typically used. Longitudinal, or time series, analyses are generally preferred since the effects of business swings and cyclical patterns can be explicitly controlled. When data for multiple parcels of land are pooled over multiple time periods, it is called a polled cross-sectional/time series analysis.

The models are usually estimated in linear (absolute) and loglinear (proportional) forms. Hedonic price models tend to introduce the most rigorous controls. As such, they are widely viewed as providing the most accurate estimates of how access to transit is capitalized into land values.

**Matched Pairs**

Matched Pairs method relies on finding comparable properties that are in every way similar except one is close to rail transit and the other is not. Finding suitable matches can be difficult. Thus, comparison properties are rarely similar enough in all respects to
suitably isolate out the unique effects of proximity to transit. For this reason, matched pairs analyses are usually applied when data and resources needed to support hedonic price modeling are not available.

**Repeat Sales Ratios**

Repeat Sales Ratios method can also be used to gauge rent premiums. Here, changes in prices and rents between two or more sales transactions for the same transit-served property are recorded. These are compared to price changes for repeat sales of properties unserved by transit to produce a ratio. The differential can be attributed to transit proximity, controlling for other factors since features of the house, neighborhood, etc. will normally remain constant in the short term. But properties that have been substantially improved over time are excluded from the analysis because the improvements could explain increases in real property values.

Knight and Trygg (1977) are among the first who tried to generalize the impacts of rapid transit systems on land use. According to them, in the context of North America, modern urban transit systems rarely, if ever, provide a major effective increase in accessibility since the areas served tend to be already more accessible by automobile. Therefore, conventional land use succession theory is not appropriate to explain the relationship between transit systems and land use. Based on a review of available literature and some firsthand observation, they found no evidence that a new transit system would increase the overall level of development of a metropolitan area.

Knight and Trygg's study was conducted over two decades ago. Since then, many more cities have built new rail transit systems (Table 1.1). Most of them are in service long enough to permit empirical studies.

Al-Mosaind, et al (1993) studied the relationship between housing sales price and distance to rail transit stations in metropolitan Portland. Applying hedonic price modeling techniques, they found a positive influence of transit to nearby properties.

Cervero (1994a) examined rail transit impacts on office and commercial land uses around suburban stations using the data for five rail stations in the Washington, D.C. and
Atlanta areas over the 1978-89 period. He found that average office rents near stations rose with transit system-wide ridership. Office vacancy rates were lower and average building densities were higher. Stations with joint development tended to capture a larger share of regional office and commercial growth than stations with no such programs did. The findings suggest that, where regional market conditions are favorable, rail transit appears capable of positive impacts on station area office markets.

Bernick and Cervero (1994) surveyed recent planning efforts to concentrate development at transit stations nationwide and compiled an inventory of recent major residential developments in station areas, suggesting the positive effects of rail transit. Shaw (1993), however, suspects that the housing market demand in station areas may not be large enough to meet the preferred supply.

Neuwirth’s (1990) qualitative examination on the impacts of rail transit on cities emphasizes the system-wide accessibility benefit of transit with the focus on downtowns. She argued that from a planning point of view, distributional shifts of development from other regions to transit corridor or station areas are also very desirable. Concentration of activity creates benefits of its own. Through the case studies of Atlanta, Boston, Dallas and Hartford, Neuwirth firstly categorized the general economic development objectives for transit investment in the cities and then examined the extent that the objectives were achieved in each city. She concluded that transit provides crucial access into highly congested downtown cores, particularly in older cities such as Boston and New York. Transit also contributes to the quality of life in urban areas, including reduction of air pollution, reduction of downtown traffic, and assistance to the transit-dependent population for access to employment and other opportunities. Although transit itself may not directly cause economic development, transit contributes in terms of providing support for growth.

The Urban Mass Transportation Administration prepares a framework for analyzing the impact of fixed-guideway transit (i.e. rapid rail, light rail, busways, and people movers) projects on land use and urban development (Emerson 1990). The scope and structure of land use impact assessment in transit feasibility analysis recommended by the framework is summarized below.
The land use impact analysis for major transit projects should be performed on three levels:

1) Impact on Regional Development; Absent convincing evidence to the contrary, all UMTA-sponsored fixed-guideway planning projects assume that mass transit investments will have no net effect on the amount of regional development.

2) Impact on Corridor Development; At the corridor level, the types and densities of land use development are considered. The analysis should clearly indicate how much growth, if any, will come from other parts of the region, giving that corridor impacts tend to be a zero-sum game.

3) Impact on Development Around Station Areas; A transit project is most likely to affect land use in areas immediately adjacent to stations. Impact analysis at station level should try to identify obstacles to development, for example, local economic conditions and land use policies.

Studies on the land use/economic development benefit of transit development have generated mixed results. Common understanding of the role of transit in land use/economic development and factors influencing the development is best summarized by Porter (1998) in the following points:

- Experience with transit-focused development shows conclusively that planning for regional development should be integrated with the design of transit systems. The most successful examples of transit-based development have been metropolitan areas where regional planning significantly influenced and integrated development patterns and the design of new transit systems. Transit-related development will take time to become a significant component of metropolitan growth patterns.

- Local governments play a fundamental role in promoting transit-related development. As the guardians of land use regulation, local governments can encourage transit-focused development through comprehensive planning policies and zoning provisions that allow or provide incentives for development densities, designs, and a mix of uses supportive of transit service.

- Station-area development generally is much a product of market strength of the region and interest in specific locations than a response to the availability of transit. Absent
support from market forces, public officials will wage an uphill fight to attract development to station areas.

- Physical characteristics of station areas influence land development in the vicinity of stations. The design of station-area developments could do more to create the pedestrian-friendly environments that increase transit ridership.

### 2.2.2 The environmental Benefits

Few empirical studies can be found from the available literature focusing at the benefits of rail transit as an alternative to auto driving. One reason could be that available data are mostly about the trips that people actually made. Although the alternative values of transit are observable, it is difficult to measure and present them in a quantitative term.

Travel demand modeling technique could help to forecast the potential modal shift from automobile to transit resulting from the improvement or new construction of transit systems so that the possible reduction of road congestion could be detected. In reality, however, the predicted shifts are often overshadowed by the rapid increase of auto trips. According to Cervero (1994b), transit’s nationwide share of total commute trips fell from 6.4 percent in 1980 to 5.3 percent in 1990. In California, while transit journeys rose in absolute numbers during the 1980s (one of the few states where this was the case), transit’s share of commute trips fell in the state’s four largest metropolitan areas, despite their new rail systems (Table 2.1).

### TABLE 2.1 Transit’s Share of Commute Trips in Four Metropolitan Regions, CA

<table>
<thead>
<tr>
<th>Region</th>
<th>1980</th>
<th>1990</th>
</tr>
</thead>
<tbody>
<tr>
<td>Greater Los Angeles</td>
<td>5.4%</td>
<td>4.8%</td>
</tr>
<tr>
<td>San Francisco Bay Area</td>
<td>11.9%</td>
<td>10%</td>
</tr>
<tr>
<td>San Diego</td>
<td>3.7%</td>
<td>3.6%</td>
</tr>
<tr>
<td>Sacramento</td>
<td>3.7%</td>
<td>2.5%</td>
</tr>
</tbody>
</table>

Source: Cervero 1994b
2.2.3 The Social Benefits
Meeting the mobility needs of the particular social groups is often stated as one of the goals of public transportation investment. Many do have mentioned the contributions of transit to the quality of life in urban areas (e.g. Neuwirth 1990, Beimborn 1993, Cervero 1994b). The social effects, however, are rarely examined and measured. The study reported by Nelson (1997) is one of the few exceptions. In the case study, Nelson estimates the savings in general social costs generated by the Metropolitan Atlanta Rapid Transit Authority (MARTA). He concluded that MARTA generated an average of about $107 million dollars annually in savings to society after considering the subsidies.

2.2.4 The Direct Employment Benefits
The direct effects of rail transit development are relatively easy to quantify and usually are identified in environmental impact statements mandated in project evaluations. For example, the implementation of Tren Urbano will generate 15,000 jobs during construction and 400 permanent positions for operation and management (USDOT/FTA et al 1995). However, these direct benefits are not considered as the main reasons for transit investment decision making (Lee and Yujnovsky 1971).

2.3 Summary and Findings
The literature on rail transit benefit analysis suggests the following common understanding: (1) Rail transit alone does not cause economic growth, although it supports and contributes to the regional development, particularly the downtowns. Its positive impacts on land use are limited in scale and mainly concentrated in station areas; (2) The contribution of rail transit to the reduction of road congestion and air pollution is observable but often overshadowed by the overall increasing level of congestion and pollution; (3) There are direct benefits from building a rail transit system, for example, creating construction and operating jobs, but these benefits are not the main reasons for rail transit investment decision making; (4) One of the primary goals of transit investment is to obtain social benefits – promoting social equity and improving the quality of life, which have not been well examined.
Chapter 3

Accessibility Measures and Applications

Accessibility to employment, services and other opportunities is an important component of the quality of life. It is also the element of the quality of life that are repeatedly modified by public policy-making related to the public and private transportation systems, and the locations of economic and public service activities. It is important for planners and policy analysts to effectively utilize accessibility measures as powerful tools for project evaluation and policy analysis.

However, the word of 'accessibility' has been used in many contexts and in different ways, for example, as a variable in location analysis, as an indicator of urban development, as input in land use-transportation modeling, or as a goal of transportation policy. The ambiguity of the notion leads to various definitions of accessibility which, consequently, results in inconsistency or even confusion in applications.

In this chapter, we review the literature in the subject of accessibility, aiming to construct an appropriate methodological framework for rail transit benefit analysis. We first survey various definitions of accessibility presented in the literature. Then, we create a typology categorizing existing accessibility measures and briefly discuss their operational properties. Finally, the applications of accessibility in transportation and planning practice are discussed.

3.1 Definitions of Accessibility:

3.1.1 Conceptualizing Accessibility

The 1970s saw a strong interest in the study of accessibility. Attempts to conceptualize accessibility can be placed into two categories according to what the authors were referring to -- people or places, as suggested by Hanson (1995). In later part of our discussion, the accessibility defined referring to people will be termed as behavior-based accessibility and that referring to places as location-based accessibility.
Hagerstrand (1974, p.5, cited in Moseley (1979, p.57)) explained that:

[accessibility has at least two sides. One is legal/social. Frequently an individual must fulfill certain requirements in terms of training, age, ability to pay, support from others and so on in order to be permitted to pass the barrier around the supply point he wants to reach. The other is the physical. He must be able to command the transportation facilities which are needed for reaching the supply points at suitable times.

Here, by accessibility, Hagerstrand meant people’s capability for accessing certain activities, constrained by their education, income, and age as well as their mobility.

When accessibility is defined referring to places, the size and type of activities (e.g. local vs. regional employment opportunities; suburban centers vs. CBDs) are usually associated with it. Links and transportation means to reach those activities are also considered the components of accessibility. For example, Morris et al. (1979) asserted that accessibility denotes the ease with which spatial distributed opportunities may be reached from a given location using a particular transportation system. Similar description was also given by Ingram (1971, p.101): accessibility is ‘the inherent characteristic, or advantage, of a place with respect to overcoming some form of spatially operating source of friction, for example, time and/or distance’.

Some other scholars tried to give a comprehensive description to accessibility. In studying the accessibility deprivation of rural Britain, Mosley (1979) argued that accessibility had three components: (i) people, the residents of rural areas; (ii) the activities or services which they require; and (iii) the transport or communication link between the two. Burns (1979) discussed accessibility in the context of “the freedom of individuals”. Whether or not the individuals participate in different activities (for example, work, shopping, and recreation) is due to the fact that the freedom of the individuals is constrained by the three components of accessibility: transportation, time, and space. The transportation component of accessibility involves the transportation available to individuals and the speed at which this transportation allows individuals to
overcome space. The temporal component involves the availability of activities at different times of the day and the times in which individuals participate in specific activities. And the spatial component involves the availability of activities in geographic space and the locations of specific activities that individuals participate in.

Recent studies generally adopt one of above definitions on accessibility and some elaborate on the concept in a more descriptive fashion. For example, Handy (1993) suggests a differentiation between local accessibility and regional accessibility to better understand the spatial structures of metropolitan regions and communities, and their impacts on non-work travel patterns as well. According to her, local accessibility is defined with respect to "convenience" establishments, such as supermarkets, drugstores, and dry cleaners. Regional accessibility, on the other hand, is defined with respect to regional retail centers, such as suburban shopping malls or downtown commercial areas. Local accessibility depends on proximity to locally oriented centers of activity, whereas regional accessibility depends on transportation links to large, regionally oriented concentrations of activity.

In sum, there is no unanimous definition for accessibility in theory. Appropriate explanations mostly rely on the intended or practical application. Nevertheless, consensus exists in the operational level and are highlighted in the following points:

- Accessibility refers to, in a broad sense, the proximity from one point to a set of points which have attributes (e.g. opportunities) associated with;
- Spatial separation constrains the number of opportunities available. People appreciate and compete for the opportunities;
- The constraints are characterized by some forms of functions of travel costs (time, distance, or monetary costs).

3.1.2 Distinguishing between Mobility and Accessibility
The concepts of mobility and accessibility are closely related and have been interchangeably used in many circumstances. While recognizing this relationship, we here
emphasize that distinguishing between the two will help better inform public debate and policy analysis on transportation and land use issues.

Put in the most succinct way, mobility refers to the ability to move between different places whereas accessibility refers to the ability to reach destination opportunities under the constraints of time or cost. Mobility depends on individuals’ physical attributes and monetary resources, the availability of transport means and appropriate infrastructure. Accessibility, on the other hand, incorporates the feature of opportunities which may or may not present as a result of the person’s move. High mobility will certainly contribute to enhancing accessibility. However, the effect of mobility on accessibility depends on the spatial distribution of opportunities. In a given environment where opportunity distribution, i.e. land use pattern, is fixed (at a particular point of time), higher mobility means higher accessibility. In a situation that an individual’s mobility is fixed (again, at a particular point of time), wider spread of the spatial activities will result in overall lower accessibility level.

The meaning of mobility is intuitively straightforward. It mainly refers to people. For example, from transportation perspective, the oft-used term ‘regional mobility’ means the ability to move of the people at aggregate in the region. In contrast, the conceptual boundary of accessibility is rather fuzzy. Accessibility may refer to people—how easily people can reach activity sites; or to places—how easily places can be reached (Hanson 1995). People-based accessibility and location-based accessibility are closely related with each other. To enjoy higher accessibility to some points or opportunities, individuals or groups of people must have either location advantages (i.e. physically close) or mobility advantage to overcome the spatial constraint. Locations with ‘easy access’ are meaningful only to those who can reach them. A location may have a high value of accessibility to one group of people but low value to others.

Therefore mobility may be interpreted as one component, or a special case of accessibility. Overemphasizing mobility or travel efficiency as a policy objective may generate undesirable outcomes, because a linear relationship between mobility improvement and motorization could be very easily perceived, which leads to excessive
automobile dependency which generates many negative side effects. This is evident in the development experience of US metropolitan areas in the past three to four decades.

3.1.3 An Example

The two diagrams in Figure 3.1 illustrate the relationships and differences between mobility and accessibility.

On the left figure, assuming that people used to travel 30-min from origin (O) to destination D1, now those people can travel to destination D2 in 30-min, or travel from O to D1 in less than 30-min. It means that those people’s mobility has been improved. When applying accessibility concept, we look at particular activities that people are involved. Let’s look at employment opportunities. Assume that there are 50 jobs in D1. People living at O used to have access to these 50 jobs in 30-min travel. As a result of the improvement of mobility, those people can reach D2 in 30-min. So they have access to 50 plus 30 → 80 jobs. Their employment accessibility is enhanced as a result of mobility improvement. But, if the 30 jobs at D2 do not exist, the total number of jobs accessible in 30-min is still 50, even though their mobility has been improved. Or, if the 30 jobs at D2 are relocated in D1, even without mobility change, job accessibility is still improved.

FIGURE 3.1: Mobility vs. Accessibility: An Example
Above example shows the relationship between people’s employment accessibility and mobility. Similarly, we can look at a place’s accessibility related to mobility.

Let’s look at the figure to the right in Figure 3.1. Suppose D is the place where a firm or company is located. Before the mobility improvement, there are 60 labor forces (at O₁) available to the firm in 30-min travel distance. After the mobility improvement, there are now $60 + 25 = 85$ labor forces in total available to the firm D. In other words, the improvement of mobility results in a larger pool of labor force, which is good to economic development. Again, if the 25 labors in O₂ do not exit, the improvement of mobility would not change the labor market size to D, at least in the short term. Or the 25 labors in O₂ relocate to O₁, without mobility change, firm’s access to labor market is still improved.

Therefore, we may conclude that accessibility can be enhanced by improving mobility, by reconfiguring the spatial distribution of activities, or by both.

### 3.2 Measurements of Accessibility

Corresponding to the variation of accessibility definitions, accessibility measures take many different forms. Each measurement method is based upon a specific interpretation of accessibility. In Figure 3.2, we create a typology of accessibility measures selected from the literature reviewed. Examples of specific formulae and references are presented for each end box in the figure. They are grouped as performance-based, potential-based, and preference-based measures.

It could be argued that, in a generic sense, all measures are performance-based, either the performance of transportation systems or land use activities (Handy 1997). In our classification, those measures are stratified by what is to be evaluated and on what theoretical grounds. The performance-based measures emphasize mobility; the potential-based measures, built on the theory of social physics, evaluate the spatial interactions of opportunities whereas preference-based measures evaluate individuals’ utility, the concept from microeconomics theories.
FIGURE 3.2: A Typology of Accessibility Measures

<table>
<thead>
<tr>
<th>ACCESSIBILITY MEASURES</th>
<th>Performance-Based Measures [on travel cost or mobility]</th>
<th>Travel Time (e.g. Allen, et al. 1992)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>( A_i = \sum_j C_{ij} ); or ( A_i = \frac{1}{n(n-1)} \sum_i \sum_j C_{ij} )</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Space-Time Prism (Burns 1979)</td>
</tr>
<tr>
<td>Potential-Based Measures [on spatial interaction]</td>
<td>Isochronic Cumulation</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>( A_i = \sum_{j \in C_i} O_j )</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(Wachs &amp; Kumagai 1973)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Supply-Side Measure</td>
</tr>
<tr>
<td></td>
<td></td>
<td>( A_i = \sum_j O_j f(C_{ij}) )</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Supply-Demand Measure</td>
</tr>
<tr>
<td></td>
<td></td>
<td>( A_i = \sum_j O_j f(C_{ij}) / D_j )</td>
</tr>
<tr>
<td>Preference-Based Measures [on utility]</td>
<td>Preference-Based Measures</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>( A_n = \frac{1}{\mu} \ln \sum_d e^{\mu U_n(d)} )</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(Ben-Akiva &amp; Lerman, 1977)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>( A_i^g = \frac{1}{\alpha} \log \left( \sum_j O_j^g e^{-\alpha C_{ij}} \right) + C )</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(Koenig, 1980)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>( A_n = \log \sum_d \left[ \exp(U_n(d) - U_n(t)) \right] )</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(Ramming, 1994)</td>
</tr>
</tbody>
</table>

Alternative measures of \( f(C_{ij}) \):
- \( f(C_{ij}) = C_{ij}^{-\alpha}, \alpha > 0 \) (Hansen, 1959);
- \( f(C_{ij}) = \exp(-\beta \cdot C_{ij}) \) (Wilson, 1971);
- \( f(C_{ij}) = \exp(-C_{ij}^2 / \gamma) \) (Ingram 1971)

\( D_j = \sum_k P_k^m f(C_{jk}) \) (Weibull 1976; Shen 1996);

\( A_i \): the accessibility evaluated for zone i; \( g \): individual or group g;
\( C_{ij} \): distance or time from zone i to zone j; \( P_k^m \): population or workers taking mode m;
\( O_j \): activities or attraction in zone j; \( \alpha, \beta, \gamma \): parameters reflecting distance deterrence.
3.2.1 Performance-Based Measures

In performance-based accessibility measures, travel costs are the only component taken into account. Travel cost takes the form of total travel time or average travel time from one place/zone to all other places/zones. The advantage of this method is that accessibility values are measured in absolute terms (e.g. minutes). Different regions or urban areas can then be compared and evaluated by the measured accessibility levels.

Burns’ (1979) development of Hagerstrand’s time-geography model can be interpreted as a mobility-centered accessibility measure. The model is a diagram, named Space-Time Prism (Figure 3.3), representing the spatial and temporal characteristics of an individual’s behavioral constraints. To a specific individual, the number, size, and location of his/her space-time prisms depend on his/her daily activity characteristics and travel speed (on foot or by a transport means). Burn proposed several strategies in terms of urban and transportation policies to reduce the constraints and, consequently, increase the accessibility of the individuals to various activities. By and large Burns’ focus was actually the individuals’ mobility.

FIGURE 3.3: Space-Time Diagram for a Individual

Confronted with Origin and Destination Coupling Constraints

Source: Burns, 1979. p.13
3.2.2 Potential-Based Measures

On the other hand, potential-based measures take both travel costs and number of opportunities into account.

The isochronic cumulating method is widely applied in practice. It counts the total number of opportunities that could be reached within a threshold travel time or distance. The effect of distance or travel time on the attractiveness of opportunities is treated the same anywhere within the threshold, and no attraction is considered from any opportunity beyond that threshold. This measure is operationally convenient and intuitively easy to interpret. However, it ignores the fact that the attractiveness of opportunities does have a distance-decay effect on a given place. When the distance (or travel cost) increases, the attractiveness of the opportunities diminishes.

The gravity-based measure was first introduced by Hansen (1959) and later modified or extended in various forms. A central ingredient in these models is the concept of potential. The early efforts were concentrated on the choice of an appropriate measure of impedance to reflect the perceived cost of travel. For example, Wilson (1971) suggests an exponential cost function instead of the power function used by Hansen. However, according to Ingram (1971), both of these distance functions tend to decay too rapidly in comparison with empirical evidence. He suggests that a modified Gaussian form is superior.

Arguing that the Hansen (as well as Wilson and Ingram) formulae are limited to considering only the “supply side” of accessibility measurement, Weibull (1976) and Shen (1996) proposed a refined framework for measuring accessibility, which takes the “demand side” - the competition for available opportunities - into account.

Specifically, when regional employment accessibility is to be measured, the refined method accounts for job competition among workers commuting by different modes, in addition to the basic two components in Hansen-type models - spatial separation and job attractiveness. The output of this measure is still a set of indices that have only relative meaning. However, it enables researchers to tell where are accessibility rich/poor location, because an accessibility value of one indicates the balance between job supply and demand in a given land use and transportation system.
3.2.3 Preference-Based Measures

Koenig (1980) was concerned that Hansen-type accessibility measurements were based on purely intuitive and common sense approaches which lack behavioral theoretical support, although they have the advantage of being simple in structure and readily understandable by non-specialists. Behavioral modeling techniques were then introduced in measuring accessibility. Nevertheless, he found that the measures like Hansen-types provide quite correct or equivalent results to behavioral theory-based measures when applied carefully. According to him, composite measures of accessibility were the most appropriate since they not only reflect transportation system conditions but also the wealth of choice provided by urban structure. Micro-economic approaches should be used for controlling the acceptability of those formulations. Thus, as shown in the formula, Hansen-type accessibility measure is kept as the central part of the model Koenig developed.

Strictly speaking, the model suggested by Koenig (1980) is still a gravity-based, Hansen-type measure of place-accessibility. A more strictly behavioral theory-based accessibility measure is the ‘expected maximum utility’, also known as ‘logsum’, proposed by Ben-Akiva and Lerman (1977). According to them, accessibility refers to some composite measure that describes the characteristics of a group of alternatives as they are perceived by a particular individual. It depends on both the alternatives being evaluated and the individual traveler for whom accessibility is being measured.

On the direction of Ben-Akiva and Lerman, Ramming (1994) developed and operationalized an accessibility model by summing up the destination utility and travel disutility gained from the potential trips made by an individual (or a group of individuals). In this context, accessibility refers to the set of activities to which a person has the potential to travel, even if such a trip is not made. The destination utility is a linear function of the attributes of that destination, such as the presence of a commercial product, the size of shops, number of jobs, etc. The travel disutility is a linear function of another set of variables associated with the level of service that existing transportation
system provides, such as in-vehicle, walk time, wait time, out-of-pocket cost, comfort, etc.

As we have discussed in previous section that location-based and behavior-based accessibility are closely related at conceptual level. Each emphasizes one aspect of the two folds of accessibility: geographic locations and individuals' behavior. Their measurement models, however, take very different forms, as seen in Figure 3.2. One may serve better than another depending on particular application purposes. In the location-based accessibility models, land use pattern and transportation service quality play a central role whereas in the behavior-based measures, individuals’ mobility is the key. Hence, with no further investigation, we may speculate that location-based accessibility is more applicable to land use or other physical environment related assessment while behavior-based accessibility measures behave better in travel demand modeling. There are trade-off associated with each type of measures in terms of measurement efficiency/accuracy and operational convenience/cost.

3.2.4 Selecting an Appropriate Accessibility Measure

Those shown in Figure 3.2 are several exemplary accessibility measures of each type. The list would be much longer if an exhaustive collection was presented. Large variations exist among the measures. The issue is to choose (or develop) an appropriate one to serve a particular application purpose, considering the advantages and shortcomings of the measures in terms of specification, calibration and interpretation when implementing them (Handy and Niemeier 1997).

Morris, et al (1979) provide a general guideline for selecting accessibility measures:

- The measure should incorporate an element of spatial separation, which is responsive to changes in the performance of the transport system.
- The measure should have sound behavioral foundations.
- The measure should be technically feasible and operationally simple.
- The measure should be easy to interpret, and preferably be intelligible to the layman.
3.3 The Application of Accessibility

The accessibility measures such as those reviewed above provide a range of means to evaluate or project levels of economic efficiency and quality of life. In application, accessibility measures can be utilized: 1) in land use-transportation modeling 2) in characterization of the urban environment; and 3) as indicators in project evaluation and policy analysis.

3.3.1 Land use-Transportation Modeling

Accessibility lies in the core of transportation-land use relationships. Virtually all models of land use-transportation interactions have to deal with the concept of accessibility, explicitly or implicitly. Detailed discussion on this topic will require exploration of the huge body of literature in the modeling arena, and hence is omitted here.

3.3.2 Characterization of Urban Environment

Accessibility is perhaps the most important concept in defining and explaining urban form and function (Wachs and Kumagai 1973). The accessibility of a site to economic and social activity centers determines its value, its economic and social uses, and the intensity of development on it. Through accessibility, there is a systematic relationship between the spatial distribution and intensity of development, and the quantity and quality of travel within a region. The differences in spatial accessibility are systematically related to such variables as age, race, sex, and location of residence within the region. Therefore, accessibility, characterizing the built environment, can be used as an explanatory variable to explore or explain many urban phenomena.

One example is the influential ‘spatial mismatch hypotheses’ proposed by Kain (1968). In examining the effects of housing segregation and regional decentralization on Black employment, Kain hypothesizes that the distance to and difficulty of reaching certain jobs from Black residence areas impose costs on the Blacks high enough to discourage them from seeking employment there. In addition, Blacks may have less information about and less opportunity to learn jobs distant from their residence. The
hypotheses have generated a large volume of literature and remain in debate in the field (e.g. Gordon, et al. 1989, Holzer 1991, Taylor and Ong 1995).

Another example is Kockelman’s (1996) investigation in the relative significance of urban form on household vehicle miles traveled (VMT), automobile ownership, and mode choice. In her study, five models are built using accessibility plus other socioeconomic variables as explanatory variables. She found that accessibility was generally very powerful. Accessibility to opportunities was very strongly associated with automobile use. This association stems from a direct effect - closer opportunities diminish trip distances, thus reducing miles traveled as well as making the automobile less of a necessity - and indirect effect, since accessibility is generally associated with higher land prices, less convenient parking options, and probably more roadway congestion. She also found that accessibility was a far better predictor of VMT and mode choice than density, which has been widely used.

Mobility and accessibility measures can also be applied for inter-city/region comparative study. Allen, et al (1992) measure and compare the overall access indices (in units of minutes) for sixty U.S. metropolitan areas. From their results, Sacramento, CA, has the highest index of 69.72 minutes while Akron, OH, has the lowest value of 30.00 minutes, suggesting that, on average, Akron is more easily accessible, or has higher mobility, than Sacramento.

3.3.3 Project Evaluation and Policy Analysis

Accessibility is an important area of urban policy-making involving explicit goals. There are major spatial and demographic differences in the accessibility of specific urban population groups to variety of economic and cultural opportunities. Accessibility indicators help redirect policy and planning toward the equalization of opportunities.

One of the main tasks that planners or policy analysts often do is to examine and evaluate the effects of urban investments or policy initiatives on the city. A ‘with/without’ or ‘before/after’ comparative analysis approach is commonly taken. Changes in accessibility due to the investment or policy can be estimated and projected to
indicate the effectiveness of the investment or policy in improving economic efficiency and quality of life.

Paaswell’s (1981) analysis on the effects of light rail transit system on the Buffalo region is an example of this type of studies. In his study, a modified Hansen-type accessibility model (by Davidson 1977) was used. He found that accessibility would change resulting from the construction of the light rail transit system, but very moderately. Given the route of the system as being constructed, travel through most zones not immediately adjacent to the system would still be based upon the highway system. It is very unlikely that existing modal split ratios would change significantly once the system is in full operation. For a portion of the public residing in those zones, there would be a significant increase in actual and perceived accessibility. Those inner city residents who do not own an automobile, or who are considered to be transit dependent should get the most benefit of improved accessibility within the immediate vicinity of the system.

the important impact of the LRRT on the downtown is not in reducing travel times, but in focusing attention on the CBD through the investment and land-use effects. This, in turn, will increase its level of attraction and then will act to improve the CBD relative accessibility.

Changes in levels of accessibility may be better quantified using more mathematically rigorous measures. For example, the utility-based measures such as the one suggested by Ben-Akiva and Lerman (1977) may be used to conduct a ‘before/after’ type of study. Specifically, accessibility is expressed as the expected maximum utility of the choice set, which is equal to the logsum of the denominator of the logit equation given different choices, household income, and the costs associated with each choice:

\[ A_n = \ln \sum_{M} e^{V_n(m)} \]

The change in accessibility is then the difference between the accessibility levels of before \((A_n^0)\) and after \((A_n^1)\) introducing a project or policy initiative. This change in accessibility can be interpreted as the change in consumer welfare and translated into
monetary terms by using *compensating variation*, \( CV_n \) (Small and Rosen 1981), known as Small and Rosen Method:

\[
CV_n = \frac{1}{\lambda} \left\{ \ln \sum_{m} e^{\nu_s^{(m)}} - \ln \sum_{m} e^{\nu_s^{(m)}} \right\}
\]

where \( \lambda \) is the marginal utility of income.

Rodier et al (1998) apply this method to measure welfare distribution among income groups in different transportation supply scenarios in the Sacramento region. Another example is Handy and Niemeier’s (1997) study, similar to Rodier et al.’s, in King County, Washington.

### 3.4 Summary and Findings

There is no unanimous definition of accessibility in the literature. Appropriate explanations mostly rely on the intended applications. Nevertheless, some degree of consensus exists at the operational level: Accessibility refers to, in a broad sense, the spatial or temporal proximity from origins to destinations with which there are attributes (e.g. opportunities) associated. Spatial separation constrains the number of opportunities available. People seek and compete for the opportunities, subject to the constraints of their physical mobility and other social and economic factors.

Accessibility levels can be measured based on the performance of the transportation systems in the region, on the potential of spatial interactions between opportunities and opportunity seeks, or on the utility attributes of opportunities and individuals’ preference to different opportunities.

In application, accessibility measures can be utilized: 1) in land use-transportation modeling 2) in characterization of the urban environment; and 3) as indicators in project evaluation and policy analysis.
Chapter 4

Job Accessibility in the SJMR

The discussion presented in previous chapters indicates that the social dimension of transit benefits has been one of the least investigated areas in the literature of transit benefit analysis, despite the fact that decision making on transit investment often places significant weight on the potential social contribution of transit systems. Accessibility is an important indicator of the quality of life, and accessibility measures provide useful tools to evaluate the effectiveness of transit investment or policy initiatives in improving the quality of life of citizens.

In this chapter, we apply the accessibility framework to rail transit benefit analysis through the case study of Tren Urbano. For the moment, we focus on the job accessibility in the SJMR, since it is an important element in people’s daily life.

As we mentioned earlier, transit benefit analysis looks at the consequences of a transit investment decision, assuming that the decision had been made or an alternative had been chosen. Decision making on rail alignment is an extremely complicated process. It should consider and balance various political, environmental, and technical concerns relating to the transit system construction and operation, for example, the locations of and connections among major employment/service centers and residential areas, the availability of vacant developable land near proposed stations, the integration with existing transportation services, the mitigation of construction impacts on local neighborhood and properties, the viability of alternative construction methods, and so forth. The Tren Urbano project is a product of 27 years of planning in the SJMR. Numerous studies have been conducted regarding alternative transportation plans and Tren Urbano alignments. The base alignment of Tren Urbano as it is now under construction was finalized in 1993 San Juan Regional Transportation Plan (Barton-Aschman Associates 1993) and evaluated in detail during the studies for environmental impact statement (USDOT 1995). Thus, in our case study presented here, we take the Tren Urbano system as given and analyze its effects on job accessibility in the SJMR.
The Tren Urbano case study consists of two parts. Part one, the rest of this chapter, measures the job accessibility in the SJMR for the 1990 base case and 2010 future cases. Accessibility is utilized as an indicator to characterize the urban structure and the transportation systems in the region, to diagnose current problems faced by different income groups in accessing jobs and to evaluate the benefits of Tren Urbano to the region as a whole and to individual income groups. Part two, presented in next chapter, identifies desirable supplemental policies and examines their effects on regional job accessibility in the presence of Tren Urbano. Policy recommendations are then offered to the local governments aiming to maximize the social and economic returns of Tren Urbano.

4.1 Methodology
A comparative study method in combining with simple simulations is used for this analysis. Comparisons of accessibility levels are made between Tren Urbano-Build and No-Build scenarios in 2010, and between 2010 Cases and 1990 Base Case. The unit of analysis is Traffic Analysis Zone (TAZ).

4.1.1 Selecting an Accessibility Measure
Selecting an appropriate measure of the employment accessibility for SJMR 1990 base case is driven by three goals at this phase of the research. Firstly, the measure should incorporate both the elements of location attractiveness and spatial separation. The former is indicated by the number of employment opportunities while the later by a impedance function of travel time or travel distance. Secondly, the measure should be operationally simple and analytically straightforward. The measurement results can then be easily understood and interpreted. Finally, the measure should make use of available data. Through the analysis of the base case, the measure either proves sufficient or suggests that additional data are needed for further studies. In either case, it will be beneficial for future research.
Guided by above goals, we choose a Hansen-Type accessibility measure for our base case study, which is expressed as the following:

\[ A_i = \sum O_j f(C_{ij}) \]

where: 
- \( A_i \): accessibility from zone \( i \) to the employment opportunities in SJMR; 
- \( O_j \): opportunities presented in zone \( j \) (e.g. number of jobs); 
- \( C_{ij} \): travel time for a trip from \( i \) to \( j \); 
- \( f(C_{ij}) \): impedance function.

The impedance function is specified below, adopted from The San Juan Regional Transportation Plan (SJRTP) (Barton-Aschman 1993):

\[ f(C_{ij}) = \alpha \cdot C_{ij}^\beta \cdot e^{\gamma C_{ij}} \]

where: \( \alpha \), \( \beta \) and \( \gamma \) are model coefficients, given by SJRTP; 
- for Home-Based Work Trips: \( \alpha = 4,106,986; \ \beta = -1.3924; \ \gamma = -0.0132 \); 
- \( C_{ij} \): the travel time from zone \( i \) to zone \( j \); \( e \): is the base of the natural logarithms.

When applying this impedance function, we set the constant \( \alpha \) to one in order to shorten computing time and save storage space. Since the accessibility is a relative measure in this case, doing so will not affect our measurement results.

4.1.2 Data Sets
The original data source is the SJRTP database created by Barton-Aschman Associates, Inc. through five major travel surveys conducted in 1990 in the San Juan Region. The data base includes travel information, land use and employment data at zonal level for 755 zones of SJMR, including:

1). Origin-Destination tables for zonal travel time and travel costs by modes and by types of trips (1990 and 2010); 
2). Major socioeconomic information such as total population, employment, median income, trip productions by types of trips and by income categories for 755 zones; 
3). Employment distribution on job distributions by four types - basic, retail, service, and government;
4). TAZ geographic boundary files;

5). Other socioeconomic information and geographic boundary files (e.g. streets, census tract boundaries, municipality boundaries) were generated by processing from the US Census 1990, and the TIGER/Line Files (1992).

4.1.3 The Tools
Since the study required intensive computation and mapping, Geographic Information System (GIS) technology was a key tool for this research. GIS was utilized to process statistical (e.g. the Censuses) and spatial data (e.g. transportation networks), and to visualize experimental and final results. ArcInfo GIS has been chosen due to its relative strong capability in manipulating and analyzing large amounts of geographic information.

4.2 Characterization of the Spatial Structure of SJMR

4.2.1 Population and Employment Distributions
The SJMR includes twelve municipalities: Bayamon, Canovanas, Carolina, Catano, Dorado, Guaynabo, Loiza, Rio Grande, San Juan, Toa Alta, Toa Baja, and Trujillo Alto (see Figure 4.1) with a total area of 401 square miles. It consists of 755 Traffic Analysis Zones (TAZs). In 1990, the SJMR had a total population of 1.3 millions and total number of employment 409,523.

Both population and employment were concentrated in the three largest municipalities - San Juan, Bayamon, and Carolina. Table 4.1 shows the population and employment by municipalities. The three municipalities account for 64.3 percent of the population and 82.6 percent of the regional employment.

Figure 4.2 displays the population distribution pattern in the San Juan region with one dot representing 300 persons. The figure shows that population concentrates in Old San Juan, Santurce, Hato Rey, and Rio Piedras. Less-dense concentrations are in the rest of San Juan, northern Carolina, central Bayamon and northern Guaynabo. From the map
FIGURE 4.1 The Geography of San Juan Metropolitan Region (SJMR)
FIGURE 4.2: Spatial Distribution of Population in SJMR (1990)

LEGEND:
- SJMR Region
- Municipality Boundary
- TAZ Boundary
- Population Distribution
  - 1 Dot = 300

0 2 4 6 Miles
FIGURE 4.3: Spatial Distribution of Jobs in SJMR (1990)
FIGURE 4.4: TAZ Level Median Household Income in SJMR (1990, Dollars)

LEGEND:
- SJMR Region
- Municipality Boundary
- TAZ-Level Median Income ($)
  - < 5000
  - 5000 - 7500
  - 7500 - 10000
  - 10000 - 12500
  - > 12500
it is observable that a north-south settlement pattern extending from Old San Juan to Rio Piedras and an east-west pattern from Bayamon to Carolina.

**TABLE 4.1 Population and Employment in the Municipalities of SJMR (1990)**

<table>
<thead>
<tr>
<th>Municipality</th>
<th>Population</th>
<th>%</th>
<th>Employment</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bayamon</td>
<td>220,262</td>
<td>16.85</td>
<td>46,931</td>
<td>11.5</td>
</tr>
<tr>
<td>Canovanas &amp; Loiza</td>
<td>66,123</td>
<td>5.04</td>
<td>9,092</td>
<td>2.2</td>
</tr>
<tr>
<td>Carolina</td>
<td>177,806</td>
<td>13.58</td>
<td>34,710</td>
<td>8.5</td>
</tr>
<tr>
<td>Catano</td>
<td>34,587</td>
<td>2.69</td>
<td>7,072</td>
<td>1.7</td>
</tr>
<tr>
<td>Dorado</td>
<td>30,759</td>
<td>2.46</td>
<td>6,341</td>
<td>1.5</td>
</tr>
<tr>
<td>Guaynabo</td>
<td>92,886</td>
<td>7.07</td>
<td>26,068</td>
<td>6.4</td>
</tr>
<tr>
<td>Rio Grande</td>
<td>45,648</td>
<td>3.48</td>
<td>3,784</td>
<td>0.9</td>
</tr>
<tr>
<td>San Juan</td>
<td>437,745</td>
<td>34.14</td>
<td>256,617</td>
<td>62.7</td>
</tr>
<tr>
<td>Toa Alta</td>
<td>44,101</td>
<td>3.2</td>
<td>2,702</td>
<td>0.7</td>
</tr>
<tr>
<td>Toa Baja</td>
<td>89,454</td>
<td>6.79</td>
<td>9,619</td>
<td>2.3</td>
</tr>
<tr>
<td>Trujillo Alto</td>
<td>61,120</td>
<td>4.7</td>
<td>6,587</td>
<td>1.6</td>
</tr>
<tr>
<td>SJMR Total</td>
<td>1,300,491</td>
<td>100</td>
<td>409,523</td>
<td>100</td>
</tr>
</tbody>
</table>

Source: Barton-Aschman, 1993

Figure 4.3 shows the spatial distribution of employment opportunities with one dot indicating 300 jobs. A similar pattern to population distribution is observed, except that it is more concentrated spatially. The core is northern and central San Juan. Other concentrations are evident in the Bayamon Town Center, the Caparra area, the airport, and scattered locations with one or more large employers. An east-west employment corridor is also observable along the major highways.

Figure 4.4 shows the median household income at the TAZ level. TAZs with medium or higher income are located in central San Juan (areas close to the interchange of PR 177 and PR 1, and to the southeast of Centro Medico), Condado tourist areas, Hato
Rey, Torrimar of northern Guaynabo, Catano, and northern Bayamon. This is a quite different spatial display of income distribution from a typical North American city where the poor are usually located in inner city whereas the affluent are in suburb.

4.2.2 Road Network and Public Transportation

The settlement pattern in SJMR described above corresponds to the spatial network structure of the region that consists of three layers of road/street system. The top one is the freeways (e.g. Expreso de Diego or 22; Autopista Luis A. Ferre or 52) which go to the west and south, and are used as lateral or cross-regional facilities. The mid-layer, which is the major framework in the current road system, consists of numbered routes (i.e. PR 1, PR 2, PR3, PR 181, etc.) that converge on San Juan from throughout the island in nearly a radial structure (Figure 4.5). The bottom layer is the local streets with various patterns. For example, within older activity centers such as Santurce, a grid pattern exists while newer areas such as Bayamon have developed typical suburban, curvilinear street patterns.

Three major modes of public transportation are provided in the San Juan Region: Publico, Metropolitan Bus Authority (AMA) and Acuaexpreso ferry.

Publico system is the largest mode of public transportation in the region. Publicos are a private, fixed-route, shared-ride car, minibus, or van service. The service operates on a demand-responsive basis and has provided reasonably consistent service frequencies, especially during peak hours. Figure 4.6 shows the Publico passenger volume distribution (1990). Publicos by law cannot serve routes within AMA's market area without AMA's expressed concurrence to the Public Service Commission (CSP). They operate largely outside the urban core of San Juan.

Scheduled bus service is operated by AMA, mostly within the Municipalities of San Juan, Carolina, and Guaynabo (Figure 4.7).

Ferry service is limited to the Old San Juan/Canato ferry.
FIGURE 4.5: Highway and Street Pattern of the SJMR (1990)

FIGURE 4.6: Publico Passenger Volume Distribution Pattern (1990) in the SJMR

FIGURE 4.7: Bus (AMA) Service Coverage in the SJMR (1990)

Source of Figure 4.5 ~ 4.7: Barton-Aschman Associates, Inc. 1993
4.3 Job Accessibility in the SJMR: 1990 Base Case

4.3.1 Regional Job Accessibility Patterns
Above descriptions illustrate an image that population and employment sectors are clustered around the northern and central San Juan and adjacent areas of Guaynabo, Bayamon, and Carolina. They are relatively well connected by the three layers of road networks, compared with the rest of the San Juan Region. Therefore, we expect that, in general, northern and central San Juan would have relatively higher employment accessibility than other areas. In the east-west corridor, areas close to PR 3 and Expresso de Diego or PR 22 should also have relative high accessibility due to the presence of the freeway or major highway facilities and services provided by the Publicos.

4.3.2 Accessibility Patterns with Different Transportation Modes
The measured employment accessibility levels associated with all transportation modes are visualized through thematic mapping using the natural breaks classification method which allows us to examine the clustering patterns of TAZs based on their accessibility scores. Figure 4.8 displays the employment accessibility level in the SJMR by the auto mode. The darker the gray tone is for a TAZ, the higher its accessibility score is, meaning that it is more accessible by automobile.

Note that a ring-belt pattern is evident from the map. The inner ring, with the highest accessibility scores, includes Old San Juan, Hato Rey, Rio Piedras, areas near Plaza Las Americas. The outer ring has medium accessibility with a few exceptions such as Bayamon Town Center areas that have higher accessibility scores. The rest of the SJMR has lower accessibility.

Automobile is the dominant mode in the region and auto access is ubiquitous. Thus, the accessibility pattern with auto mode will demonstrate the characteristics of the structure and land uses of the built environment. As described before, SJMR has a radial road framework with jobs highly concentrated at the core. A ring-belt accessibility (with auto mode) pattern is to be expected.
On the other hand, accessibility patterns with public transportation modes will reflect the relative level of service provided by the modes, in addition to those of land use and road structure. This is illustrated by Figure 4.9 and 4.10, showing the accessibility scores computed for Publico and AMA (bus) mode respectively.

The accessibility with Publico mode shows a scattered pattern. High accessibility areas are observed in Bayamon Town Center, Rio Piedras and central-west of Carolina where regional Publico terminals are located. The principle explanation for the scattered accessibility pattern with Publico mode (compared with the ring-belt pattern with auto mode) is the demand-responsive service feature of Publico. An east-west corridor with medium accessibility score is also observable from the map. It corresponds to the job distribution pattern along the east-west major highways (PR 3 and Expresso de Diego).

The accessibility measured with AMA mode shows a north-south stripe pattern. High accessibility areas are those along PR 1 or Avenida Luis Munoz Rivera corridor. That is because that AMA service is mainly provided in San Juan and adjacent areas.

4.3.3 TAZ Accessibility Scores by Income Classification

Table 4.2 reports the population-weighted average accessibility scores for five TAZ groups classified by zonal median household income (1990). The value of the scores indicates the accessibility level for a specific transportation mode. Although the scores are unit free and have no intrinsic meaning given the nature of the gravity-based model, they do allow us to compare the relative accessibility level between different groups, modes, and scenarios. For example, the auto mode achieves the highest regional average accessibility score (3763) while bus (AMA) mode has the lowest (304). This pattern is also observed for each of the five income groups. It makes sense since, for the same region where the spatial distribution of employment and the transportation network are both fixed, the calculated accessibility scores with different modes simply represent the difference in travel impedance. Automobile generally provides higher spatial mobility than bus does.

The index columns contain the scores normalized to the regional average for each mode and income group. An index value greater than one means that people in those
### TABLE 4.2: 1990 Base Case: Population-Weighted Average Accessibility Scores and Indices

<table>
<thead>
<tr>
<th>Income Group</th>
<th>High</th>
<th>Med. High</th>
<th>Medium</th>
<th>Med. Low</th>
<th>Low</th>
<th>Region</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&gt;$12.5K %</td>
<td>$10-12.5K %</td>
<td>$7.5-10K %</td>
<td>$5-7.5K %</td>
<td>&lt;$5K %</td>
<td>Population</td>
</tr>
<tr>
<td>Population</td>
<td>215950</td>
<td>17</td>
<td>192601</td>
<td>15</td>
<td>360060</td>
<td>28</td>
</tr>
<tr>
<td>Jobs</td>
<td>103111</td>
<td>25</td>
<td>51644</td>
<td>13</td>
<td>93468</td>
<td>23</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Modes</th>
<th>Scores</th>
<th>Index</th>
<th>Scores</th>
<th>Index</th>
<th>Scores</th>
<th>Index</th>
<th>Scores</th>
<th>Index</th>
<th>Scores</th>
<th>Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>Auto</td>
<td>5450</td>
<td>1.45</td>
<td>3809</td>
<td>1.01</td>
<td>3347</td>
<td>0.89</td>
<td>3150</td>
<td>0.84</td>
<td>3624</td>
<td>0.96</td>
</tr>
<tr>
<td>Publico</td>
<td>966</td>
<td>1.32</td>
<td>718</td>
<td>0.98</td>
<td>624</td>
<td>0.85</td>
<td>689</td>
<td>0.94</td>
<td>757</td>
<td>1.03</td>
</tr>
<tr>
<td>AMA</td>
<td>484</td>
<td>1.59</td>
<td>260</td>
<td>0.86</td>
<td>184</td>
<td>0.60</td>
<td>250</td>
<td>0.82</td>
<td>449</td>
<td>1.48</td>
</tr>
<tr>
<td>Combined a</td>
<td>1101</td>
<td>1.43</td>
<td>761</td>
<td>0.99</td>
<td>672</td>
<td>0.87</td>
<td>755</td>
<td>0.98</td>
<td>903</td>
<td>1.17</td>
</tr>
</tbody>
</table>

*Combined: Combined public transportation. Obtained by choosing the shortest total travel time among all possible public modes for each pair of zones.*
FIGURE 4.8: Job Accessibility Pattern in the SJMR (Auto Mode)
FIGURE 4.9: Job Accessibility Pattern in the SJMR (Publico Mode)
FIGURE 4.10: Job Accessibility Pattern in the SJMR (Bus Mode)
FIGURE 4.11: Job Accessibility Pattern with Public Transportation in the SJMR (2010 Tren Urbano Build Scenario)
FIGURE 4.12: Job Accessibility Change with Public Transportation in the SJMR (Between 1990 Base and 2010 Tren Urbano Build Scenario)
zones have higher employment accessibility than the regional average level and are in advantageous locations in terms of accessing job opportunities, compared with those in zones with the index values less than one.

For the auto mode, the High Groups (income > $10K) has accessibility indices above the regional average whereas the Low Groups (income < $7.5K) below the average. For the transit modes--buses (AMA), the Publicos and the two combined, higher accessibility scores are observed at both ends of the income spectrum. In general, the lower income groups have smaller index value than the higher income groups.

This observation is also showned by overlaying the income distribution map with accessibility maps. Mid- or higher income households are clustered in Torrimar (northern Guaynabo), areas around the interchange of PR 1 and PR 177. Accessibility scores in these areas are high by Publico mode and not low by auto mode. An exception is the areas starting from the terminal of Acuaexpreso to the east along the canal. Those are where squatters live and have high accessibility geographically but low income.

4.4 Job Accessibility in the SJMR: the 2010 Tren Urbano Build and No-Build Cases
The Base Case results conform to our knowledge about the region, suggesting the appropriateness of the selected accessibility measure. We then apply the same measure to 2010 Tren Urbano Build and No-Build Cases. Since we are mainly interested in the effects of the Tren Urbano, the discussions that follow will focus on the public transportation modes.

Figure 4.11 illustrates the accessibility level with the combined public transportation mode in the 2010 Tren Urbano Build Case. It shows that accessibility is generally the highest in zones near the Tren Urbano (Phase One). Apparently, the rail transit system plays a dominant role in enhancing employment accessibility in the region. Figure 4.12 displays the change in accessibility from the 1990 Base to the 2010 Build Case. The darker the tone, the higher the increment in accessibility level. Similarly, the zones near the Tren Urbano alignment enjoy the greatest gains.

Table 4.3 reports the results for the year 2010 cases. Compared with the results for the Base Case, the following observations are made:
<table>
<thead>
<tr>
<th>Income Group</th>
<th>High $&gt;12.5K %</th>
<th>Med. High $10-12.5K %</th>
<th>Medium $7.5-10K %</th>
<th>Med. Low $5-7.5K %</th>
<th>Low &lt;$5K %</th>
<th>Region %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population</td>
<td>249088 16</td>
<td>207575 13</td>
<td>428648 28</td>
<td>420416 27</td>
<td>238394 15</td>
<td>1544121 100</td>
</tr>
<tr>
<td>Jobs</td>
<td>118149 24</td>
<td>59143 12</td>
<td>118430 24</td>
<td>91648 19</td>
<td>104754 21</td>
<td>492097 100</td>
</tr>
</tbody>
</table>

### 2010 Tren Urban Build Case

<table>
<thead>
<tr>
<th>Modes</th>
<th>Scores</th>
<th>Index</th>
<th>Scores</th>
<th>Index</th>
<th>Scores</th>
<th>Index</th>
<th>Scores</th>
<th>Index</th>
<th>Scores</th>
<th>Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>Auto</td>
<td>6335</td>
<td>1.42</td>
<td>4771</td>
<td>1.07</td>
<td>4001</td>
<td>0.89</td>
<td>3698</td>
<td>0.83</td>
<td>4472</td>
<td>1.00</td>
</tr>
<tr>
<td>Publico</td>
<td>977</td>
<td>1.33</td>
<td>761</td>
<td>1.03</td>
<td>629</td>
<td>0.86</td>
<td>641</td>
<td>0.87</td>
<td>820</td>
<td>1.11</td>
</tr>
<tr>
<td>AMA</td>
<td>526</td>
<td>1.45</td>
<td>405</td>
<td>1.11</td>
<td>263</td>
<td>0.73</td>
<td>258</td>
<td>0.71</td>
<td>521</td>
<td>1.43</td>
</tr>
<tr>
<td>Rail</td>
<td>955</td>
<td>1.73</td>
<td>587</td>
<td>1.06</td>
<td>415</td>
<td>0.75</td>
<td>463</td>
<td>0.84</td>
<td>515</td>
<td>0.93</td>
</tr>
<tr>
<td>Combined a</td>
<td>1562</td>
<td>1.46</td>
<td>1118</td>
<td>1.04</td>
<td>876</td>
<td>0.82</td>
<td>916</td>
<td>0.85</td>
<td>1151</td>
<td>1.07</td>
</tr>
<tr>
<td>Publico b</td>
<td>860</td>
<td>1.35</td>
<td>661</td>
<td>1.03</td>
<td>543</td>
<td>0.85</td>
<td>551</td>
<td>0.86</td>
<td>719</td>
<td>1.13</td>
</tr>
<tr>
<td>Combined a, b</td>
<td>1371</td>
<td>1.37</td>
<td>976</td>
<td>0.98</td>
<td>761</td>
<td>0.76</td>
<td>791</td>
<td>0.79</td>
<td>1012</td>
<td>1.01</td>
</tr>
</tbody>
</table>

### 2010 Tren Urban No-Build Case

<table>
<thead>
<tr>
<th>Modes</th>
<th>Scores</th>
<th>Index</th>
<th>Scores</th>
<th>Index</th>
<th>Scores</th>
<th>Index</th>
<th>Scores</th>
<th>Index</th>
<th>Scores</th>
<th>Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>Auto</td>
<td>6335</td>
<td>1.42</td>
<td>4771</td>
<td>1.07</td>
<td>4001</td>
<td>0.89</td>
<td>3698</td>
<td>0.83</td>
<td>4472</td>
<td>1.00</td>
</tr>
<tr>
<td>Publico</td>
<td>890</td>
<td>1.31</td>
<td>700</td>
<td>1.03</td>
<td>577</td>
<td>0.85</td>
<td>601</td>
<td>0.88</td>
<td>771</td>
<td>1.13</td>
</tr>
<tr>
<td>AMA</td>
<td>381</td>
<td>1.61</td>
<td>217</td>
<td>0.92</td>
<td>140</td>
<td>0.59</td>
<td>180</td>
<td>0.76</td>
<td>371</td>
<td>1.57</td>
</tr>
<tr>
<td>Combined a</td>
<td>950</td>
<td>1.34</td>
<td>712</td>
<td>1.00</td>
<td>595</td>
<td>0.84</td>
<td>622</td>
<td>0.88</td>
<td>816</td>
<td>1.15</td>
</tr>
</tbody>
</table>

*a Combined: Combined public transportation. Obtained by choosing the shortest total travel time among all possible public modes for each pair of zones.

*b Measured using 2010 travel time information but 1990 job data for Publicos
1) At the regional scale, the overall employment accessibility level with public transportation mode is enhanced (from an average score of 770 in year 1990 to 1073 in year 2010). If controlling the job distribution pattern and opportunity level (i.e. measuring the accessibility using 2010 estimated trip time data but 1990 job distribution information), the 2010 Build case still has higher regional average score (999) than the Base Case (770). This is due to the increased mobility provided by the Tren Urbano, and the improvement in other public transportation services. The worst case is the 2010 Tren Urbano No-Build, with a much lower score (709) even when the effect of job increase is included, suggesting the importance of the Tren Urbano to the region.

2) At a finer scale, all income groups are better off in the Tren Urbano-Build Case but worse off in the Tren Urbano-No-Build Case from the 1990 Base. Take the LOW group as an example, by public transportation, its average accessibility score in year 1990 is 903 while in year 2010 Build and No-Build cases the scores are 1151 and 816, respectively. Same trend is observed for all other income groups.

3) The normalized indices show that, for most income groups, the construction of the Tren Urbano will not substantially change their relative levels of accessibility with respect to the regional average. A noticeable exception is the MEDIUM-HIGH group (with income between $10K and $12.5K), whose normalized score shifts from below the regional average in 1990 to above in 2010.

4) The differences among the groups in the magnitude of the index change indicate that the benefits of building the Tren Urbano, measured in terms of accessibility enhancement, are not evenly distributed with the higher income zones gain somewhat more on average than the lower income zones do. For example, the LOW group's accessibility index drops from 1.17 of 1990 level to 1.07 of 2010 and the MEDIUM-LOW from 0.98 to 0.85. On the other hand, the HIGH group's value increases from 1.43 to 1.46 and the MEDIUM-HIGH group from 0.99 to 1.04. (It should be pointed out that the income classification for the 2010 Case is still based on the 1990 income information and does not account for possible spatial redistribution of income groups in the future. Furthermore, the amount of benefits eventually gained by each group is largely determined by the actual ridership.)
5) The enhancement in employment accessibility in the region is due to the construction of the Tren Urbano, improvement in bus (AMA) services, and employment growth. The level of services of the Publicos actually deteriorates by year 2010. This is shown from the calculated accessibility scores for the Publico mode. When controlling the jobs (i.e. using 1990 job distribution data), the accessibility level goes down from 732 in year 1990 to 639 in year 2010. (This result is based on the outcome of the 1993 SJRTP models. Recently, a more rigorous planning for the Publicos and bus systems in the SJMA has been in process.)

4.5 Summary and Findings

4.5.1 The 1990 Base Case Study
For the 1990 Base Case, job accessibility is measured for all transportation modes. The resulting accessibility pattern associated with each mode is analyzed in considering the features of the SJMR built environment and the service characteristics of each mode. Measured job accessibility results are also examined for five TAZ groups classified by the 1990 median household income -- High (>12,500), Medium High ($10,000-$12,500); Medium ($7,500-$10,000); Medium Low ($5,000-$7,500); and Low (<$5,000). The main findings are:

i. Measured accessibility patterns conform with our qualitative knowledge about the Region, suggesting that our chosen accessibility measure is applicable to this analysis.

ii. At the aggregate level, due to their location patterns, the lower income groups are in a relatively disadvantageous situation in terms of job access, compared with the higher income groups. There are needs for the lower income people to improve their accessibility to jobs in the Region.

iii. The provision of job accessibility by public transportation, especially those with fixed-guideways, is geographically constrained, that is, the accessibility effects created by public transportation are confined around station areas and along system alignments.
4.5.2 The 2010 Tren Urbano-Build and No-Build Case Studies

At the regional scale, the overall job accessibility of transit users is enhanced due to the introduction of Tren Urbano. The worst case is the 2010 Tren Urbano No-Build, with a much lower accessibility level even when the effect of job increase is included. At a finer scale, all income groups are better off in the Tren Urbano-Build Case but worse off in the Tren Urbano-No-Build Case from the 1990 Base.

Geographically, the impact of Tren Urbano alone on job access is highly localized in the areas along the track alignment. Zones close to Tren Urbano experience the highest gain. Thus, integrating rail with other transportation modes is essential, not only for the interests of higher rail transit ridership, but also for geographically extending the benefit of Tren Urbano.

Among the social groups, the higher-income gains slightly more on average than the lower-income due to the location patterns of these groups. The result is based on the 1990 income classification and does not account for possible spatial re-distribution of income groups in the future. It indicates that, if the land use pattern (in terms of job and population distribution across the Region) remained unchanged from 1990 to 2010, the discrepancy in job accessibility via public transportation systems between higher and lower income groups would be likely to increase. To optimally redistribute the accessibility benefits of Tren Urbano among the social groups, land use policies become the key.
Chapter 5

Policy Scenario Analysis and Policy Recommendations

A concern has been raised from the analysis presented in the previous chapter: The limitations of transit in improving accessibility may extend from the geographical dimension to the social dimension due to the location characteristics of different population groups. The relative job accessibility of the lower income groups would decrease if existing land use patterns in the SJMR remained unchanged. It calls for policy intervention to channel the accessibility benefits toward those lower income groups.

By definition, accessibility contains two components: transportation system and opportunities to be reached through the transportation system. Altering the value of either or both will change accessibility level. Therefore, there are two basic approaches to enhancing job accessibility: mobility improvement and land use reconfiguration.

5.1 Mobility Approach to Improve Job Accessibility

5.1.1 Transportation Policy Scenario Design

Mobility improvement can be achieved by increasing the level of services provided by transit. A number of factors affect the level of transit services, including coverage, routes, fare, travel time (in-vehicle time and access time) and service frequency (affecting average wait time).

Coverage and routes are determined during planning or design periods and do not change frequently. Enlarging service coverage and/or increasing service routes obviously will help improve overall accessibility level in a given region. In this study, to design scenarios that are comparable to previous analysis, we assume that the coverage and routes of the three main public transportation modes in the SJMR -- Publico, bus (AMA), and Tren Urbano would be fixed through the year 2010. The detailed features of the three
modes were specified in the 1993 San Juan Regional Transportation Plan (SJRTP) (Barton-Aschman 1993).

Fare rate is usually regulated. Changes in the fare of one mode will affect travel demand for that mode and for other modes as well, depending on the substitutability among the modes. These changes in demand will in turn influence the operating plans, which will consequently influence individuals' travel behavior and eventually affect their accessibility to opportunities. Fare rate change has greater impact on low-income people than on others. Again, in this analysis, we do not consider this type of effect assuming that fare rate would be fixed.

From the system operating perspective, the most commonly studied policy variable is travel time. If the travel time by all transit modes could be reduced significantly, accessibility in the region would certainly be improved. Unfortunately, this is often not feasible (at least in the short term) due to budget constraints and institutional difficulties. To make recommendations to the local transit agencies on which mode(s) they should focus in order to achieve the goal of improving job accessibility, we need to examine the sensitivity of reducing travel time of each mode on regional accessibility. Accordingly, we design the following scenarios for the three public modes: All else being equal, how would job accessibility change if the level of service of the bus mode were improved by a ten-percent reduction in zonal travel time? We shall pay attention to two effects resulting from travel time reduction: (i) the change in average accessibility level in the Region and for individual groups; and (ii) the change in relative accessibility of each income groups. Similarly, what would the accessibility outcomes be if only Publico travel time were reduced by ten percent? Same question is asked for the rail mode, i.e. Tren Urbano. The 2010 Tren Urbano-Build Case is used as base case.

A ten percent reduction in zonal travel time by each mode can be achieved by increasing operating speed, reducing wait time (i.e. increasing service frequency), shortening transfer time (such as better station connection, scheduling, or fare integration), or all of above. It is important to point out that the investment required to achieve ten percent reduction in zonal travel time would be certainly different among the
three modes. Here we focus on their accessibility effects and omit the discussion on related cost-benefit issues associated with each mode.

5.1.2 Effects of Mobility Policy on Job Accessibility

The effects of transit service improvements on job accessibility are reported in Table 5.1. As shown in the table, at the regional level, a ten-percent reduction in zonal travel time by rail (all else being equal) has the greatest effect on regional aggregate job accessibility (an increase in accessibility score from 1073 to 1196). The result of Publico service improvement is close to that of rail with an increase in job accessibility from 1073 to 1178. However, a ten-percent reduction in zonal bus travel time has little effect on regional job accessibility (a change of score from 1073 to 1099). Similar effects are observed for individual Traffic Analysis Zone (TAZ) groups. The principal explanation to this result is that the geographic coverage of bus system in the SJMR is small. The improvement of service quality can hardly affect overall regional accessibility level.

For individual income groups, service improvements by rail and Publico have different effects on the changes of their relative accessibility levels. The discrepancy in accessibility levels between the lower and higher income groups will be reduced with Publico service improvement but increased with rail service improvement. This is indicated by the changes in the index values, which are the ratios of group accessibility scores over the regional average. For example, in the 2010 Build Case, the job accessibility indices for the High and the Low income groups are 1.46 and 1.07, respectively, with a difference of 0.39. With ten percent reduction in Publico travel time, the indices are 1.43 and 1.08, respectively, with a difference of 0.35. On the other hand, with ten percent reduction in rail travel time, the indices are 1.48 and 1.06, respectively, with a difference of 0.42. This is because, like bus systems, rail service is also highly geographically constrained. Zones near rail stations benefit more from the service than those farther away. We should emphasize again that this discrepancy could extend from geographical to social dimension if people were “stuck” with their residential locations.

On the other hand, Publico is flexible and has a relatively large service coverage. Improving Publico service will enhance regional job accessibility without increasing the
difference among the income groups. Technically, reducing Publico time is relatively
easier to achieve than reducing rail time because the existing service level of Publico is
low (Lau 1997). In the SJMR, the difficulties in improving Publico service come from
institutional aspects, rather than technical ones (Lau 1997). For the brand new rail system,
the opportunity for further increasing the operating speed would be quite little. Therefore,
reducing rail time would have to rely on reducing wait time or increasing service
frequency, which could significantly increase operating costs.

5.2 Land Use Approach to Improve Job Accessibility

The premise of changing job accessibility through land use policies is that, for a given
transportation system, accessibility could be improved by clustering job opportunities and
individuals at the locations closer to the system. The spatial distribution of job demand
and supply is then transformed into a setting with which accessing jobs becomes more
efficient by transit. Therefore, we would expect that the equity issue raised earlier on the
Tren Urbano case could be eased or resolved provided transit users could relocate to the
places closer to stations.

Many have voiced for metropolitan accessibility improvement through land use
include improving pedestrian walking environment; development densification; job-
housing balance; and land use mix. Nevertheless, there are heated debates on how
practical it is to implement these strategies in major U.S. metropolitan areas given the
restricted existing development conditions and the political environment (Gordon, et al.
1991, Giuliano 1995). In studying the San Juan case, we design policy scenarios by
experimenting with these strategies.

Transportation policies such as those discussed above are usually carried out at
the regional scale. On the other hand, land use actions typically take place at the local
level given the decentralized structure of land use control in the SJMR (Dorison and
Enrique 1996). When analyzing the effects of land use policies on improving job
accessibility, we focus on the micro scale strategies, i.e. the land development policies in
### TABLE 5.1: Effects of Transit Service Improvements on Job Accessibility

<table>
<thead>
<tr>
<th>TAZ Groups by 1990 Income Classification</th>
<th>Region</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>High $&gt;$12.5K %</td>
<td></td>
</tr>
<tr>
<td>Med. High $10-12.5K$ %</td>
<td></td>
</tr>
<tr>
<td>Medium $7.5-10K$ %</td>
<td></td>
</tr>
<tr>
<td>Med. Low $5-7.5K$ %</td>
<td></td>
</tr>
<tr>
<td>Low $&lt;$5K %</td>
<td></td>
</tr>
<tr>
<td>Scores Index</td>
<td>Scores Index</td>
</tr>
<tr>
<td>1990_Base</td>
<td>770</td>
</tr>
<tr>
<td>1562</td>
<td>1.00</td>
</tr>
<tr>
<td>2010_Build</td>
<td>1073</td>
</tr>
<tr>
<td>1683</td>
<td>1.00</td>
</tr>
<tr>
<td>Modes If with 10% Total Travel Time Reduction on Individual Mode from the 2010 Build Case:</td>
<td></td>
</tr>
<tr>
<td>Publico</td>
<td></td>
</tr>
<tr>
<td>Bus</td>
<td></td>
</tr>
<tr>
<td>Rail</td>
<td></td>
</tr>
<tr>
<td>Scores Index</td>
<td>Scores Index</td>
</tr>
<tr>
<td>1683</td>
<td>1178</td>
</tr>
<tr>
<td>1591</td>
<td>1099</td>
</tr>
<tr>
<td>1766</td>
<td>1196</td>
</tr>
<tr>
<td>1.43</td>
<td>1.08</td>
</tr>
<tr>
<td>1.45</td>
<td>1.09</td>
</tr>
<tr>
<td>1.48</td>
<td>1.06</td>
</tr>
</tbody>
</table>

Note:

Results are for combined public transportation, which is obtained by choosing the shortest total travel time among all possible public modes for each pair of zones. Between each pair of zones, only one mode, whichever is available and has the fastest service, is considered. In real world, however, zonal trips may involve multiple modes. Consequently, the results shown above may underestimate the effects of travel time reduction on job accessibility for all scenarios.
station areas. These areas are also termed as Transit Land Use Impact Zone (TLUIZ) (Cevero, 1994a).

In the following sections, we first discuss how the Transit Land Use Impact Zones should be properly defined. Based on the suggested definitions, we introduce a Walkability Index to evaluate the pedestrian walking environment near stations, which is one of the key aspects of transit station area land use planning. Next, several policy scenarios are designed to analyze land use impacts on regional job accessibility.

5.2.1 Defining Transit Land Use Impact Zone

In transit planning, one-quarter-mile or five minutes walking distance from all directions to the station is commonly used in determining service areas or projecting transit ridership. To transportation planners this is the acceptable walking distance to transit stops. Beyond that distance another connecting mode is required or public transit will not be used for the trip (Gray and Hoel 1992).

The rationale of defining transit service areas lies with individuals’ walking behavior – how far people are willing to walk to/from transit stations. Empirical evidence has shown that people's walking behavior varies depending on the walk trip purpose, physical environment, socioeconomic background, and other factors (Gray and Hoel 1992). In his in-depth examination on Americans' walking behavior, Untermann (1984) has shown that most people were willing to walk 500 feet, 40 percent will walk 1,000 feet, and only 10 percent will walk half a mile.

In analyzing rail transit's impacts on the land use in the vicinity of transit lines, most scholars have taken the one-quarter-mile distance as given, although some others have used different figures, for example, one-third-mile (Moon 1990) or 500 meters (Al-Mosaind, et al 1993).

For demonstrative purpose, in this study, we use one-quarter mile distance in defining station areas or the Land Use Impact Zone. Given the variation in people’s walking behavior, which figure to use (one-quarter mile or one-third mile from stations, or other figures) is not the real issue. What matters is how the distance is to be measured: using Euclidean distance or actual walking distance.
Most studies have used Euclidean distance due to its operational convenience. Still some have shown that using actual walking distance provided better results in both micro-level application such as determining transit service area (Azar and Ferreira 1994) and in macro-level application such as building metropolitan housing sales price model (Chen 1994). we recommend the actual walking distance for the reasons beyond the improvement in measurement accuracy.

First, the actual walking distance reflects the real impacted areas since it has been assumed that the spatial extent of transit’s influence on land use activities is bounded by pedestrian walking range. For any given station, the impact zone measured with actual walking distance is always smaller than that measured with the Euclidian distance due to the physical constraints of the built environment facing pedestrians.

The second advantage of using walking distance measure is that the quality of the built environment in terms of pedestrian friendliness can be represented and evaluated.

Nevertheless, each measure can be utilized to serve different purposes. The Euclidean distance-based measure indicates the expected impact zone (by the definition) whereas the actual walking distance-based measure is the observed or actual impact area. Therefore, we suggest that the former be applied for planning purpose while the latter for empirical analysis purpose.

In the next section, we demonstrate an application of distinguishing between the expected and observed transit impact zones by constructing a Walkability Index to evaluate pedestrian walking environment in station areas.

5.2.2 Evaluating Station Area Walking Environment

Physical conditions have been identified as one of the four major factors influencing land use development in station areas (Knight and Trygg 1977, Sriver 1993). A pedestrian friendly station environment could be a crucial element to make a station development successful (Bernick and Cevero 1994). A well designed station area encourages people’s use of the system. In a sense, changing station area land configuration is a combination of mobility and land use approach to indirectly improve job accessibility.
Mapping out people's walking paths starting from stations at a given distance or in a given time clearly illustrates the physical configuration characteristics of the urban context in which stations locate, as shown in Figure 5.1. In addition to the visual examination, the stations' physical environment can also be evaluated in a quantitative term, which we call the 'Walkability Index' (WI). It is defined as the ratio of the area of the observed impact zone (in the actual walking distance) over the area of the expected impact zone (in the Euclidean distance). The distances can be measured in terms of either space (e.g. one-quarter-mile or 400 meters) or time (e.g. five minutes at a certain pace). The larger the index value, the more walkable the station area is.

It is not difficult to show that the value of this index depends on the coverage and the form of street networks (i.e. the walking paths) only. Whether defining the impact zone as one-quarter-mile or one-third-mile walking distance does not have an effect on the value of WI. It is worth to note several extreme cases: i) For a station that has no pedestrian access, the WI of the station area is zero, the minimum; ii) For a station that has perfect pedestrian access, for example, the station is located at an open land and people can access the station from any direction with direct link, the index value is one; iii) For a standard grid system (which is recommended by the Neo-Traditional Neighborhood Designers), the index value is 0.60 (see end note on calculation of the WI).

Using walking distance measure also allows us to perform more sophisticated measure of pedestrian environment quality. Since the actual pedestrian walking paths are used, it is possible to attach the attributes of the physical environment (e.g. sidewalk width, planting, illumination, and other elements of design quality) to each path/link. These attributes all have effect on people's walking behavior.

Station area design is largely the work of architects and urban designers. At the system-wide scale, we recommend the use of the Walkability Index to evaluate the walking environment of station areas and provide inputs for architects and urban designers. A station with a value of 0.6 WI or higher could be considered pedestrian-friendly. As an example, we map out the "expected" and "actual" land use impact zones for the proposed Tren Urbano stations (Figure 5.1). The road network data are from 1992 Census TIGER/Line Files and do not necessarily accurately reflect the existing walking
FIGURE 5.1: Evaluation of Station Area Walking Environment: Example of Tren Urbano in the SJMR
environment. The result, however, illustrates the application of the proposed WI. For instance, San Alfonso Station has a WI of 0.65 whereas Las Lomas Station has a WI of only 0.27, suggesting that San Alfonso Station is much more pedestrian-friendly than Las Lomas Station in terms of physical access to and from the stations.

5.2.3 Land Use Policy Scenario Design
As mentioned before, the idea of land use approach to improving job accessibility is to increase land development intensity around transit stations so that the spatial distribution of job demand and supply is altered and accessing jobs becomes more efficient or convenient by transit. Accordingly, three land use strategies are considered. These are increasing development intensity, encouraging mixed land use composition, and improving land configuration to make the areas more pedestrian friendly. Specifically, the accessibility effects are examined for the following scenarios: (i) What if the vacant developable land was developed at a gross residential density of 10 units per acre, which is the desirable minimum density for transit operation, or 18 units per acre, which is the desirable average density for Transit-Oriented Development (Calthorpe 1993). (ii) What if the number of job opportunities in station areas increases by ten-percent. Or (iii) what if (i) and (ii) are combined. Station area land configuration is actually a design issue and has been discussed earlier (At this stage, we are unable to quantify the effects of improvement in walking environment on regional job accessibility).

Existing Land Use in the Tren Urbano Phase I Station Areas
To design the policy scenarios, we first assemble the land use information in the areas around 16 Tren Urbano Phase I stations. Using GIS we create a quarter-mile buffer around each of the 16 stations. All of the TAZ's that partially or entirely fall into the buffer are considered as candidate zones for possible future land use policy actions.

Station areas consist of both built-up and vacant land. we focus on the vacant, developable land in the areas for policy scenario analysis. In reality, existing built-up areas can also be redeveloped or in-filled to achieve higher development intensity.
Table 5.2 summarizes the land resources in the Tren Urbano Phase I station areas. The land categories include urbanized and vacant for the unconstrained and total land. As specified in the SJRTP (1993), the development of a land area is constrained or prohibited if its slope is in excess of 35%, or if it is within the area of flood plain delineated by the Puerto Rico Planning Board, or if it appears in the inventory of critical wildlife areas provided by the Puerto Rico Department of Natural Resources. Therefore, the land reported as "Unconstrained Vacant", or often called vacant developable land, is available for future new development. It accounts for 1197.7 acres in the station areas of Tren Urbano Phase I. In the SJRTP (1993), no specific development recommendations are made to these areas. Our policy scenario designed below is based on hypothetical development strategies over this amount of vacant developable land.

Assumptions
There are two underlying assumptions in performing the above scenario analysis. One is that, aside from the amount of growth in population and jobs forecasted by SJRTP (1993) for the period of 1990-2010, there would be no extra growth resulting from building Tren Urbano in the SJMR. Therefore, the scenarios designed above imply the redistribution of population or jobs from the 2010 cases studied and presented in previous chapter. This assumption is consistent with the literature reviewed in chapter two, which suggests that a rail transit system alone may not generate new growth but may cause the redistribution of regional development.

The other assumption is that, under each of the proposed development policies, population or jobs in the region would redistribute to the proposed density level. In reality, this is not necessarily the case because households' and firms' location decisions are determined by many other factors in addition to transportation. Therefore, these scenarios are just some simplified extreme cases. Nevertheless, they are still useful demonstrations of analyzing the changes in accessibility resulting from land use policies.

The question now becomes from which zones the increased population or jobs would come. Once again, a simple procedure, rather than rigorous land use modeling, is
TABLE 5.2: Station Area Characteristics by TAZ Groups in Tren Urbano Phase I

<table>
<thead>
<tr>
<th>TAZ Groups by 1990 Income Classification</th>
<th>Phase I Station Areas</th>
<th>Region</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>7</td>
<td>6</td>
</tr>
<tr>
<td>40074</td>
<td>38</td>
<td>2468</td>
</tr>
<tr>
<td>38640</td>
<td>37</td>
<td>14269</td>
</tr>
<tr>
<td>40285</td>
<td>34</td>
<td>4106</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Land Areas (acres)</th>
<th>Phase I Station Areas</th>
<th>Region</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unconstrained Urbanized</td>
<td>2563.4</td>
<td>45</td>
</tr>
<tr>
<td>Unconstrained Vacant</td>
<td>435.3</td>
<td>36</td>
</tr>
<tr>
<td>Total Urbanized</td>
<td>2563.4</td>
<td>44</td>
</tr>
<tr>
<td>Total Vacant</td>
<td>435.3</td>
<td>34</td>
</tr>
<tr>
<td>Planning Area</td>
<td>2998.6</td>
<td>42</td>
</tr>
</tbody>
</table>

Source: Author's calculation based on the data from the Tren Urbano Office, San Juan, Puerto Rico
applied due to the time and data limitations. It is expressed by the following two equations:

\[ G = \sum_{i} g_i = \sum_{i} a_i * D * H \quad \text{for all } i \text{ in station areas} \] (5-1)

Where, 
- \( G \): Total population gain in Tren Urbano Phase One station areas
- \( g_i \): the population gain in zone \( i \) for all \( i \) in station areas
- \( a_i \): the area of the vacant developable land in zone \( i \)
- \( D \): development density in units per acre
- \( H \): average number of persons per unit.

\[ m_i = G * \frac{(p_i^1 - p_i^0)}{\sum_i (p_i^1 - p_i^0)} \quad \text{for all } i \text{ NOT in station areas} \] (5-2)

Where, 
- \( G \): Total population or job gain in Tren Urbano Phase One station areas
- \( m_i \): the population loss in zone \( i \) for all \( i \) NOT in station areas
- \( p_i^0 \): the total population in zone \( i \) in 1990
- \( p_i^1 \): the total population in zone \( i \) in 2010

The households or jobs relocated to the station areas would come from other zones that are not in the quarter-mile buffer of stations. Equation (5-1) means that the gain in households or jobs by each zone in station areas is determined by the amount of vacant developable land presence in that zone. Equation (5-2) means that the loss of households or jobs by each zone not within the buffer is proportional to that zone's share of forecasted growth between 1990–2010.

**5.2.4 Effects of Land Use Policy on Job Accessibility**
Under each of the three scenarios designed above, regional accessibility level is recalculated by applying the same model as in previous analysis. Once again, the results are
reported for the region at aggregate and for the five TAZ groups that are classified in the same scheme as the 1990 Base Case. It should be noted that the classification now refers to locations (i.e. TAZ zones) only, not to the population groups because we are simulating the scenarios that people and/or jobs relocate from zones far away from Tren Urbano to zones near the 16 stations.

Table 5.3 shows the results of scenario one: a policy of maintaining a gross residential density of 10 or 18 units per acre on the vacant developable land in the Phase I station areas. All else being equal to the 2010 Tren Urbano Build Case, the regional accessibility level would increase from 1073 to 1124 or 1165, respectively. The accessibility levels for all of the five TAZ groups would also increase. These changes in accessibility are due to the effects of population redistribution under the policies. The explanation is as follows: under this scenario, we have assumed fixed attributes of the transportation systems (i.e. bus, rail and Publico) and the job distribution pattern (which are the only components of the Hansen accessibility model). The calculated raw accessibility score of each TAZ should be identical to that in the 2010 Tren Urbano Build Case. The reported scores for the region and for each TAZ group are the population-weighted average accessibility levels. Since individuals were "attracted" from zones with lower accessibility to zones in station areas with higher accessibility, the population-weighted average accessibility would increase.

Also shown in the Table 5.3 are the directions of population flows, which is worth special attention from the land use policy making perspective. They are reported in the row "Pop +/- From 2010". A negative value means net population loss in the TAZ group in the SJMR, and vise versa. For example, the TAZ's in the Med. Low group contain 197.7 acres of vacant developable land in station areas. If the land were developed for residential use at a density of 10 units per acres, there would be an increase in population by 6425 on average (197.7[acres] x 10 [units per acre] x 3.25 [persons per unit] = 6425 persons) in the area from the forecasted 2010 level. However, in the Med. Low group, there are also TAZ's that are not in station areas. In net, the TAZ's in the Med. Low group would lose population by 9557, even though those TAZ's that are in station areas in the same group would experience a population gain (by 6425).
### TABLE 5.3: Effects of Increasing Development Intensity on Job Accessibility (in Tren Urbano Phase I Station Areas)

<table>
<thead>
<tr>
<th>TAZ Groups by 1990 Income Classification</th>
<th>Region</th>
</tr>
</thead>
<tbody>
<tr>
<td>Med. Income (1990)</td>
<td></td>
</tr>
<tr>
<td>High $&gt;12.5K %</td>
<td></td>
</tr>
<tr>
<td>Med. High $10-12.5K %</td>
<td></td>
</tr>
<tr>
<td>Medium $7.5-10K %</td>
<td></td>
</tr>
<tr>
<td>Med. Low $5-7.5K %</td>
<td></td>
</tr>
<tr>
<td>Low &lt;$5K %</td>
<td></td>
</tr>
<tr>
<td>Population (2010)</td>
<td>Region</td>
</tr>
<tr>
<td>249088 16</td>
<td>1544121 100</td>
</tr>
<tr>
<td>207575 13</td>
<td></td>
</tr>
<tr>
<td>428648 28</td>
<td></td>
</tr>
<tr>
<td>420416 27</td>
<td></td>
</tr>
<tr>
<td>238394 15</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Accessibility Level in 2010 Build Case</th>
<th>Region</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accessibility</td>
<td></td>
</tr>
<tr>
<td>1562 1.46</td>
<td>1073 1.00</td>
</tr>
<tr>
<td>1118 1.04</td>
<td></td>
</tr>
<tr>
<td>876 0.82</td>
<td></td>
</tr>
<tr>
<td>916 0.85</td>
<td></td>
</tr>
<tr>
<td>1151 1.07</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Gross Residential Density for New Development: 10 units per acre</th>
</tr>
</thead>
<tbody>
<tr>
<td>Units Increased</td>
</tr>
<tr>
<td>4353</td>
</tr>
<tr>
<td>2270</td>
</tr>
<tr>
<td>1860</td>
</tr>
<tr>
<td>1977</td>
</tr>
<tr>
<td>1517</td>
</tr>
<tr>
<td>Pop +/- From 2010</td>
</tr>
<tr>
<td>9222</td>
</tr>
<tr>
<td>5402</td>
</tr>
<tr>
<td>-4705</td>
</tr>
<tr>
<td>-9557</td>
</tr>
<tr>
<td>-362</td>
</tr>
<tr>
<td>Total Residents</td>
</tr>
<tr>
<td>258310 17</td>
</tr>
<tr>
<td>212977 14</td>
</tr>
<tr>
<td>423943 27</td>
</tr>
<tr>
<td>410859 27</td>
</tr>
<tr>
<td>238032 15</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Accessibility Scores Index</th>
<th>Region</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accessibility</td>
<td></td>
</tr>
<tr>
<td>1647 1.47</td>
<td>1124 1.00</td>
</tr>
<tr>
<td>1161 1.03</td>
<td></td>
</tr>
<tr>
<td>907 0.81</td>
<td></td>
</tr>
<tr>
<td>960 0.85</td>
<td></td>
</tr>
<tr>
<td>1193 1.06</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Gross Residential Density for New Development: 18 units per acre</th>
</tr>
</thead>
<tbody>
<tr>
<td>Units Increased</td>
</tr>
<tr>
<td>7835</td>
</tr>
<tr>
<td>4086</td>
</tr>
<tr>
<td>3348</td>
</tr>
<tr>
<td>3559</td>
</tr>
<tr>
<td>2731</td>
</tr>
<tr>
<td>Pop +/- From 2010</td>
</tr>
<tr>
<td>16600</td>
</tr>
<tr>
<td>9724</td>
</tr>
<tr>
<td>-8470</td>
</tr>
<tr>
<td>-17203</td>
</tr>
<tr>
<td>-651</td>
</tr>
<tr>
<td>Total Residents</td>
</tr>
<tr>
<td>265688 17</td>
</tr>
<tr>
<td>217299 14</td>
</tr>
<tr>
<td>420178 27</td>
</tr>
<tr>
<td>403213 26</td>
</tr>
<tr>
<td>237743 15</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Accessibility Scores Index</th>
<th>Region</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accessibility</td>
<td></td>
</tr>
<tr>
<td>1711 1.47</td>
<td>1165 1.00</td>
</tr>
<tr>
<td>1193 1.02</td>
<td></td>
</tr>
<tr>
<td>932 0.80</td>
<td></td>
</tr>
<tr>
<td>998 0.86</td>
<td></td>
</tr>
<tr>
<td>1228 1.05</td>
<td></td>
</tr>
</tbody>
</table>

Note:

For San Juan Metropolitan Area, the average number of residents is 3.25 per unit (1990 US Census)
When cross-checking these results with the spatial distribution of income groups in 1990, we see that the TAZ's in High and Med.High groups with higher accessibility level would have net in-flow of population and others with lower accessibility level would have net out-flow. This is a desirable outcome. It indicates the opportunities to ease the potential accessibility equity issue raised in the previous study because the lower income people who used to live the zones with lower job accessibility could relocate to station areas (with supportive policies or subsidies) and enjoy higher accessibility as a benefit from Tren Urbano.

Table 5.4 shows the results of scenario two and three. As expected, increasing job opportunities in station areas would also result in a higher regional job accessibility level. Combining the two, i.e. mixed land use, would have greater effect on job accessibility enhancement. This is because that, under the assumed scenarios, a larger portion of population would live close to stations and jobs would be more accessible by the transit systems.

Of course, as pointed out earlier, these are simplified, ideal cases. Households' location and relocation decisions are limited by many social and economic constraints. Even though the lower income people are willing to move, other factors may prevent them from relocating. For example, higher income communities generally do not welcome the moving in of lower income families for various concerns. Nevertheless, it is this area that policy makers should consider to looking into to generate better outcomes for the society as a whole. In the next section, we offer several policy recommendations.

5.3 Implications and Policy Recommendations

5.3.2 Policy Recommendations

(a) Develop high-flexibility transportation systems as complements to rapid rail transit. In the context of San Juan this means paying particular attention to the Publico service improvement and/or, if necessary, providing similar van services by public transportation
TABLE 5.4: Effects of Land Use Change on Job Accessibility (in Tren Urbano Phase I Station Areas)

<table>
<thead>
<tr>
<th>TAZ Groups by 1990 Income Classification</th>
<th>Region</th>
</tr>
</thead>
<tbody>
<tr>
<td>High $&gt;$12.5K %</td>
<td>Med. High $10-12.5K$ %</td>
</tr>
<tr>
<td>1990_Base</td>
<td>1101</td>
</tr>
<tr>
<td>2010_Build</td>
<td>1562</td>
</tr>
</tbody>
</table>

Accessibility

If with 10% Increase in Job Opportunities from the 2010 Case in Station Areas:

<table>
<thead>
<tr>
<th>Scores</th>
<th>Index</th>
<th>Scores</th>
<th>Index</th>
<th>Scores</th>
<th>Index</th>
<th>Scores</th>
<th>Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>1612</td>
<td>1.47</td>
<td>1144</td>
<td>1.04</td>
<td>1045</td>
<td>0.95</td>
<td>937</td>
<td>0.85</td>
</tr>
</tbody>
</table>

If with Increase in both Jobs and Residential Density from the 2010 Case in Station Areas:

<table>
<thead>
<tr>
<th>Scores</th>
<th>Index</th>
<th>Scores</th>
<th>Index</th>
<th>Scores</th>
<th>Index</th>
<th>Scores</th>
<th>Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>1701</td>
<td>1.48</td>
<td>1189</td>
<td>1.03</td>
<td>1045</td>
<td>0.91</td>
<td>984</td>
<td>0.85</td>
</tr>
<tr>
<td>1769</td>
<td>1.48</td>
<td>1223</td>
<td>1.02</td>
<td>1044</td>
<td>0.87</td>
<td>1023</td>
<td>0.86</td>
</tr>
</tbody>
</table>

Note:

Results are for combined public transportation which is obtained by choosing the shortest total travel time among all possible public modes for each pair of zones.
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phase I</td>
<td>69</td>
<td>17</td>
<td>38</td>
<td>29</td>
<td>17</td>
<td>$10,671</td>
<td>96240</td>
</tr>
<tr>
<td>Phase I-A</td>
<td>1198</td>
<td>1.2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>$10,030</td>
<td>14358</td>
</tr>
<tr>
<td>Phase II</td>
<td>105009</td>
<td>25.6</td>
<td>22659</td>
<td>5.5</td>
<td>18470</td>
<td>$8,065</td>
<td>69846</td>
</tr>
<tr>
<td>Phase III</td>
<td>7058</td>
<td>2.7</td>
<td>582</td>
<td>0.2</td>
<td>6324</td>
<td>$10,539</td>
<td>16998</td>
</tr>
<tr>
<td>Phase IV</td>
<td>5709</td>
<td>7.2</td>
<td>546</td>
<td>0.7</td>
<td>3687</td>
<td>$8,452</td>
<td>20482</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SJMR</td>
<td>79093</td>
<td>1.1</td>
<td>100760</td>
<td>3.5</td>
<td>86800</td>
<td>1.4</td>
<td>3352</td>
</tr>
</tbody>
</table>

Source: Author's calculation based on the data from the Tren Urbano Office, San Juan, Puerto Rico
agencies. The service should be well integrated with Tren Urbano in terms of coverage, route design, fare structure, physical connections, schedules, and other service features.

(b) Encourage higher land development intensity in station areas. For residential development, a minimum gross density of 10 units per acre in station areas is highly recommended. For non-residential uses such as commercial and office buildings, higher FAR should be encouraged. Large surface parking surrounding stations, which is a common practice to accommodate the demand for park-and-ride, is an undesirable development pattern. Vertical parking facilities should be provided when the demand for park-and-ride is high.

(c) Promote mixed land use in station areas. Providing mixed land use activities in station area development is more effective than single uses in improving job accessibility. Attention should be directed toward providing affordable housing and the types of jobs that are more compatible to the skills and educational background of lower income households. Therefore, lower income households have opportunities to relocate to areas with higher job accessibility by public transit.

(d) Create pedestrian-friendly station environments. A pedestrian-friendly station environment helps improve the image of rail transit as a commuting mode. At the system-wide scale, a Walkability Index (WI) can be used to evaluate the walking environment of station areas and provide inputs to architects and urban designers. A station with a value of 0.6 WI or higher can be considered pedestrian-friendly.

5.3.3 Implications for the Phasing Strategies of Tren Urbano Extensions
Due to the limitations in data sources and constraints in time, we were not able to model the accessibility effects of Tren Urbano under different extension alternatives. However, our analysis on the 2010 Cases certainly sheds lights on the phasing strategies of Tren Urbano extensions.
Should joint development in station areas be the immediate concern, Phase II (extension to Carolina) is the best choice because of the availability of large amount of vacant developable land (2,121 acres) close to the stations (Table 5.5). On the other hand, Phase III (extension to Old San Juan) provides direct access to 6.1 percent of jobs in the SJMR, rail services five percent of the Region's population plus to tourist trips to the historical areas. It has greater potential to generate large fare revenue. Certainly this option has priority among the three extension alternatives in the short term.

5.4 Summary
There are two basic approaches to improving job accessibility: mobility improvement and land use reconfiguration. With the mobility approach, three scenarios are analyzed. In each scenario, a ten-percent reduction in zonal travel time is assumed for one of the three transit modes. With the land use approach, three strategies are studied. The first is to increase development intensity in station areas. The second is to encourage mixed land use. And the third is to improve the land configuration to make the areas more pedestrian friendly.

At the regional level, all else being equal, a ten percent reduction in zonal travel time by rail (i.e. Tren Urbano) has the greatest effect on improving job accessibility. The result of Publico service improvement is close to that of rail. On the other hand, a ten percent reduction in zonal bus travel time has little effect on the regional job accessibility.

For individual income groups, service improvements of rail and Publico result in different job accessibility changes. The discrepancy in accessibility level between the lower and higher income groups will reduce with Publico service improvement but increase with rail service improvement.

As expected, increasing residential density or job opportunities in station areas would all result in a higher level of regional job accessibility. Combining the two has even greater effect on job accessibility enhancement. A pedestrian-friendly station environment helps improve the image of rail transit as a commuting mode.

The station area, or termed the land use impact zone, can be defined using Euclidean distance or actual walking distance. The Euclidean distance measures the
expected impact zone (by definition) whereas the actual walking distance measures the observed or actual impact area. we suggest that the former be applied for planning purpose while the latter for empirical analysis purpose. At the system-wide scale, a Walkability Index (WI) can be used to evaluate the walking environment of station areas and provide inputs to architects and urban designers. A station with a value of 0.6 WI or higher can be considered pedestrian-friendly.
Chapter 6

Conclusions

6.1 Implications of the Research Findings

Transit is one type of transportation technologies reflecting the efforts of human being to overcoming spatial separations between locations of residences, workplaces and other activities. It serves the same purpose as automobile or other transportation means in terms of reducing spatial friction, but it differs from automobile in various aspects such as investment decision processes, system operation, resulting spatial accessibility patterns, targeted clients, and so forth. In the U.S. context, ever since transit lost its role to automobile as the dominant mode of intraurban travel, more weights have been placed on the social, environmental and political concerns than on the economic returns of the investments in transit decision making. Accordingly, transit benefit analysis needs to address a broader range of issues or of transit induced consequences than does the conventional, economics theory-based cost-benefit analysis.

The social dimension of transit benefits has been one of the least investigated areas in the literature of transit benefit analysis. It is very much concerned with social distribution of potential gains from transit investment. The operational features of public transportation systems create a site or route-specific pattern of accessibility distribution. In other words, the contribution of transit to spatial accessibility improvement is geographically concentrated, or constrained. Unlike automobile access which is more ubiquitous, public transportation systems provide services only on selected routes through a limited number of zones. The services provided by rail are even more spatially limited: The train can only run where the tracks go and track coverage is generally limited. To facilitate intraurban travel, rail transit systems are built up traversing existing neighborhoods or urban areas. For the heavy rail systems like Tren Urban, tracks are fully grade separated, either on elevated structures or underground, to ensure required rail operating speed, safety, and other service quality. Thus, construction cost, in addition to capital and operating costs, is very high. There are also very complicated political
processes involved in track alignment plan. Consequently, rail tracks, once constructed, are nearly impossible to relocate.

The geographical limitations of transit in improving accessibility may extend to the social dimension due to the locational characteristics of different population groups—those who live closer to stations will benefit more than others who are farther away. Major transportation investment can contribute to enhancing regional accessibility in aggregate. However, the mobility provision alone does not necessarily promise by itself to strengthen the spatial competitiveness of those with specific transportation needs, because what matters is not only the absolute but also the relative level of accessibility. Inequalities in physical mobility and spatial accessibility among different population groups contribute to the social and economic inequalities, and have long been critical transportation and planning issues. Introducing a new transportation system does not guarantee resolving these issues. More efforts should be made to channel the potential benefits of public transportation investment toward socially-targeted population groups.

By conventional definition, accessibility includes two elements: opportunity distribution and transportation system. Thus, accessibility can be enhanced by improving mobility, or by integrating land use activities, or both. Fully integrating the new rail system with existing transportation modes is essential, not only for the interests of higher rail transit ridership, but also for geographically extending the positive effects of building the system.

Compared with automobile, public transportation is in a competitively disadvantageous position in terms of mobility provision. Therefore, to enhance the transit-dependent population's accessibility, land use strategies become the key. The experience in North America indicates that the outcome of implementing a rail transit system is greatly affected by many other factors, particularly land use policies (Sriver 1995, Porter 1998).

Through the three case studies in the SJMR, the 1990 Base Case, the 2010 Tren Urbano-Build and No-Build cases, and policy scenario analysis, we have shown that accessibility measure proved to be a useful analytical tool. It can be utilized to summarize the characteristics of the built environment and transportation services, to examine the
role of public transportation in enhancing regional job accessibility, to reveal the needs for supplementary policies to maximize the social returns of transit investment, and to illustrate the effectiveness of these policy alternative.

6.2 Challenges to and Opportunities in San Juan

This analysis has delivered a message that, without additional transportation and land use policies to support Tren Urbano, the benefits of the investment in this rapid transit system would be limited, both geographically and socially.

At least two factors account for this potential problem. The first factor is the service nature of transit, as discussed before. Tren Urbano will certainly improve accessibility in the SJMR once the system is in operation. But, as shown from our studies of the 2010 Build Case and on the transportation policy scenarios, the impact of the rail system alone is highly localized in the areas along the track alignment.

The second factor is the land use patterns in the SJMR. Tren Urbano alignment (Phase I) goes through the six major urban centers of the SJMR. Due to historical reasons, mid- and higher-income groups as well as jobs are also located near these centers and thus close to the proposed stations. The lower income groups, on the other hand, are relatively farther away from the system.

Nevertheless, there are great opportunities for policy makers to intervene in order to maximize the social benefits of Tren Urbano. From transportation planners’ perspective, there are untapped potentials to further improve Publico service and interface better with Tren Urbano. (Our study is based on the outcome of the 1993 SJRTP models. Recently, a more rigorous planning for the Publicos and bus systems in the SJMR has been in process.) From the land use planners’ perspective, there are nearly 1200 acres of vacant developable land near Tren Urbano Phase I stations. Our experimental analyses on different policy scenarios have shown encouraging results (Section 5.2). The challenge is how the local governments can better correspond with the region-wide transportation policies and implement effectively station area development initiatives, in order to achieve the goal of improving the quality of life for the entire society while targeting the middle and lower income groups through public investments. A number of relevant
studies have been or are being conducted by other members of the research team of the Tren Urbano Project. For example, Bar (1997) investigates fare integration policies to improve multimodal connections to Tren Urbano. Lau (1997) and Randall (1998) suggest strategies to improve the existing transit systems in the SJMR, namely the Publicos and the Acuaexpresso (ferry) systems. Plank (1998) proposes new approaches to transit marketing. At the regional scale, Coloma (1998) examines the economic development opportunities brought about by Tren Urbano. At the local scale, Sriver (1995) reviews lessons of station area land developments from other U.S. metropolitan regions and applies them to the SJMR. More specifically, Yue (1998) investigates the location efficiency mortgage strategy to promote transit supportive housing in the Region.

6.3 Contributions of This Research

The primary contribution of this research is the application of accessibility framework to analyzing the social benefit of rail transit, through a case study of Tren Urbano, an ongoing rail project in SJMR. Combining two bodies of literature—transit benefit analysis and accessibility, this research pays specific attention to the social dimension of transit induced consequences, an area that has been less investigated than others such as the land use and economic development. This topic is particularly important in current environment that the emphasis of national transportation policy has shifted from mobility-supply to accessibility-centered strategies to achieve a broader range of societal objectives, including congestion management, improved air quality, economic development and equity, as suggested by recent transportation-related legislation: the Intermodal Surface Transportation Efficiency Act (ISTEA 1991) and the Clean Air Act Amendments (CAAA 1990) (Pas 1995).

At the time when the Phase I of Tren Urbano is under construction and extension plans are in consideration, this research provides the local governments and transit agencies of SJMR with timely information on the social consequences of Tren Urbano in terms of job access. The research explicitly raises the issue of spatial and, potentially, social inequity associated with the development of the system. It also offers important advice in designing region-wide, multi-modal transportation plans and in formulating
long-term land use development strategies. All these help maximize the social and economic returns of Tren Urbano investment and improve the quality of life of the people in the SJMR.

Another contribution of the thesis is the development of the Walkability Index using GIS to evaluate the pedestrian friendliness of the built environment. With GIS, spatial and non-spatial data from various sources can be efficiently combined, re-assembled and visualized to support more rigorous analyses in a more intuitive way. The introduction and discussion on Walkability Index in the thesis also help clarify the concept of ‘transit impact zone’, which is mostly defined based on ‘the rule of thumb’ in existing literature and current practice, and shed light on other relevant studies of transit station area design and development.

6.4 Directions for Future Studies
There are at least three areas that warrant further study. The first is to analyze the interactive relationship between Tren Urbano and land use activities. Major transportation investment such as Tren Urbano will alter regional accessibility. Improved accessibility creates development potentials, which in turn generate further transportation demand. In this study, when examining the effects of land use strategies on regional job accessibility, we applied a simple method to relocate workers or jobs. Ideally, the land market’s response to Tren Urbano under various policy scenarios should be modeled in a more rigorous manner.

The second is to improve accessibility measures to better capture individuals’ characteristics and preference for different transportation modes. The limitation of a Hansen-type accessibility measure is that it is difficult to interpret the calculated accessibility changes in more intrinsic terms such as dollars or minutes. It is then difficult to quantify the differences among wider range of policy scenarios and to conduct finer-grain policy sensitivity analysis.

The third is to automate accessibility analysis procedure in a GIS environment. In this study, GIS has proved to be a useful tool to assist analysts to link and process geographical and statistical information, and to visualize the experimental and final
results. Nevertheless, the whole procedure of accessibility analysis is very data-intensive and time-consuming. Ideally, these steps should be integrated into a smooth procedure in a user-friendly GIS environment.

Automating accessibility analysis procedure also has important implications for technology transfer—one of the main objectives of the Tren Urbano Project. With automated procedures, the analytical methods and tools, in addition to current analysis results, can be delivered to the local agencies. When more data are available and new factors are taken into account, accessibility analysis can be performed by local analysts in a more timely fashion.
End Note: Transit impact zone and Calculation of Walkability Index (WI)

Assume that we are interested in a distance of \( r \) to a station.

The transit impact zone within the Euclidean distance of \( r \) to the station is \( r^2 \pi \). The transit impact zone within the walking distance of \( r \) varies depending on the structure and coverage of the pedestrian network. To illustrate the idea of WI, we choose a special case -- a uniform grid network system. The grid spacing can be assumed a fraction of the specified distance, say \((1/n)\) \( r \) (see Figure 6.1, the top half). Let’s imagine each grid cell as a city block. Then the region a pedestrian can reach on foot from the station is

\[
2n(n-1)(r/n)^2 = [2r^2 - \frac{2r^2}{n}].
\]

The WI is then

\[
\frac{[2r^2 - \frac{2r^2}{n}]}{r^2 \pi} = \frac{2 - \frac{2}{n}}{\pi},
\]

which is sensitive only to the network density (determined by \( n \)). A special case relating to grid network is that, when \( n \) is 4 and \( r \) one quarter-mile (assuming average city block is 100 meter in width), the index value is approximately 0.5.

Note that a line does not have an area. We can assume that the accessible area is the buffer zone along a path with half-block in depth (see Figure 6.1, the bottom half). It can be shown that the index value for the special case related with grid network is

\[
\frac{2 - \frac{2}{n}}{\pi} \approx 0.6 \text{ when } n \rightarrow \text{ bigger.}
\]
FIGURE 6.1: Transit Impact Zone and Calculation of Walkability Index

Example:
Transit impact zone in a distance of $r$ to the station with a block size of $(1/n)r$
Reference Cited


APTA (American Public Transit Association), 1996, *Transit Fact Book*


Barr, J.E. 1997. *Intermodal Fare Integration: Application to the San Juan Metropolitan Area*. MST Thesis, Massachusetts Institute of Technology

Barton-Aschman Associates, Inc. 1993. *Regional Transportation Plan - San Juan, Puerto Rico*


Shen, Qing, 1996. *Location Characteristics of Inner-City Neighborhoods and Employment Accessibility of Low-Wage Workers*. The Joint International Congress of Association of Collegiate Schools of Planning and Association of European Schools of Planning, Toronto


Zhang, Ming, Qing Shen, and Joseph Sussman, 1998, *Job Accessibility in the San Juan Metropolitan Region -- Implications for Rail Transit Benefit Analysis*, Transportation Research Record 1618:22-31

Zhang, Ming, Qing Shen, and Joseph Sussman, 1999, *Strategies to Improve Job Accessibility – A Case Study of San Juan Metropolitan Region*, Transportation Research Record (forthcoming)
Appendix A:

Technical Documentation

A.1 ArcInfo AML for Data Processing

This appendix contains ArcInfo (7.1.2) Macro Language (AML) codes written for data processing routines for the research on job accessibility in the San Juan Metropolitan Region. Conditions to run the codes are specified within the macros.

/* Code Name: tgr2bg.aml
/* Remarks:
/* This macro is prepared to process TIGER/Line files to generate
/* Census Block Group coverage since it was not available from local
/* agencies or commercial venders. Generating other polygon coverage
/* such as census tract can also use this code by using different
/* boundary attributes.
/* Written by: Ming Zhang, June 1997

/* Run this macro AFTER processing the row TIGER Files using "tigerarc".
/* See ArcInfo manual for detail on the usage of "tigerarc".
/* e.g. tigerarc /mit/qingshen2/ming/coverage/021/tgr72021.f5 tgr021line

&label begin
&setvar tgrname := [response 'Enter the name of the TIGER coverage']
&if [exists %tgrname% -cover] &then
 &do
  build %tgrname% line
  joinitem %tgrname%.aat %tgrname%.acode %tgrname%.aat %tgrname%-id
    %tgrname%-id

 &setvar .covname := [response 'Enter the name of the new coverage']
 copy %tgrname% %covname%

/* NOTE: check item type for ctbna before running the following macro.
/* Run tgr2bgtabla.aml, if the item is named as ctbna90l or ctbna90r.
/* If the item is named as ctbnal or ctbnar (depending on the version of
/* TIGER/Line Files), continue.

 additem %.covname%.aat %.covname%.aat bgright 15 15 i
 additem %.covname%.aat %.covname%.aat bgleft 15 15 i

 additem %.covname%.aat %.covname%.aat blkright 4 4 c
 additem %.covname%.aat %.covname%.aat blkleft 4 4 c

tables
 select %.covname%.aat
 calculate bgright = ctbnar
 calculate bgleft = ctbnal

 move blkr to blkrigh
 move blkl to blkleft
reselect blkr > ' '
change blkright o 000

select %.covname%.aat
reselect blk1 > ' ' 
change blkleft o 000

select %.covname%.aat

alter blkright, blkright, 4, i, blkri, quit
alter blkleft, blkleft, 4, i, blkle, quit

calculate bgright = bgright * 10 + blkright / 1000
calculate bgleft = bgleft * 10 + blkleft / 1000

quit

arcedit
display 9999
mape %.covname%
edit %.covname% arc
draw env arc
draw
select bgleft eq bgright
set draw 3
draw select
delete
save
quit

       build %.covname% poly
create labels %.covname%

&tty

/* At the prompt, enter the following procedures.
/* pullitems %.covname%.aat rightid
 /* pulling following items:
 /* rpoly#
 /* bgright
 /* %.covname%
 /* end

/* pullitems %.covname%.aat leftid
 /* pulling following items:
 /* lpoly#
 /* bgleft
 /* %.covname%
 /* end

/* &return

            additem %.covname%.pat %.covname%.pat bg90 15 15 i
tables
select rightid
calculate %.covname%# = rpoly#
sort %.covname%

select leftid
calculate %.covname%# = lpoly#
sort %covname%
quit

joinitem %covname%.pat rightid %covname%.pat %covname%
    %covname%-id
joinitem %covname%.pat leftid %covname%.pat %covname%
    %covname%-id
tables
select %covname%.pat
calculate bg90 = bgright

reselect bg90 = 0
calculate bg90 = bgleft

select %covname%.pat
&setvar cntycode := [response 'Enter the county code']
calculate bg90 = %cntycode% * 10000000 + bg90
kill rightid
kill leftid
quit
&end
&else
&do
    &type The coverage "%tgrname%" does not exist.
    &setvar reply := [response 'Continue? y/n']
    &if %reply% = y &then
        &goto begin
&end

/* Code Name: alteritem.aml
/* Remarks:
/* This macro is to alter item definition in TABLES.
/* Written by: Ming Zhang, July 1997

&label begin
&setvar .covname := [response 'Enter the name of the coverage']
select %covname%.aat
calculate %covname%-id = %covname%-id + 100000000
alter %covname%-id,%covname%-id,12,b,iterID,quit

&setvar continue := [response 'Done! Work with a new coverage? y/n']
&if %continue% = y &then
&goto begin

&return
&end
A.2 C Codes for Accessibility Calculation and Data Manipulation

This appendix contains the C codes written to process the data sets obtained from the local agencies and to calculate accessibility scores for all TAZ’s in the San Juan Metropolitan Region.

We took a step by step approach and each step is an independent mini-program. Doing so allows us to check the intermediate results conveniently. The Code #6 is for Weibull Shen accessibility model (i.e. demand-adjusted). It was not applied to the study presented in this thesis but included here for reference.

Two steps to calculate zonal accessibility scores:

STEP 1: run code "clacAccess.c" to generate an accessibility value for one TAZ to every other TAZ.

STEP 2: run code "calcAsum.c" to sum up the accessibility value for each TAZ. The sum is the accessibility score for the TAZ.

Code #1:

/**************************** calcAccess.c **************************
File Name: calcAccess.c
Purpose: Calculate the accessibility index for each O-D pair.
Date Created: 03-19-97
Created by: Ming Zhang
Date Modified: 
Modified by:
Remarks: Two input files are needed and should be in appropriate layout format:

1). Employment/job distribution, e.g. emptotal.txt/jobtypes.txt; and

2). Travel time O-D tables, e.g. ttimesample. The travel time data file is in the format generated by code 'utility.c'.

The output file generated by this code can be used to calculate the total score of accessibility through another procedure.

*******************************************************************************/

#include <stdio.h>
#include <math.h>
define size 800

double exp (double x);
float calcFriction (float);

struct empdata
{
    int tazid;
    int basic;
    int retail;
    int service;
    int gov;
int emptot;
} emp[size];

struct access
{
    int FromTAZ;
    int ToTAZ;
    float ttime;
    float Ffactor;
    float Abasic;
    float Aretail;
    float Aservice;
    float Agov;
    float Avalue;
} A;

main ( )
{
    FILE *infileemp, *outfileemp, *infilett, *outfilett;

    int i, j;
    float x, y;

    char infileempName[25], outfileempName[25], infilettName[25],
        outfilettName[25];

    /* Read in employment data.
       Example:
       infileemp
         fopen("/mit/qingshen2/ming/program/jobtypes.txt", "r");
       outfileemp
         fopen("/mit/qingshen2/ming/program/jobtypes.out1", "w"); */

    printf("Enter the name of the input employment data file: ");
    scanf ("%s", infileempName);

    if ((infileemp = fopen(infileempName, "r")) == NULL)
    {
        printf("The file does not exist!\n");
        exit(0);
    }

    printf("Enter the name of the output employment file: ");
    scanf ("%s", outfileempName);

    outfileemp = fopen(outfileempName, "w");

    for (i=0; i<=size; i++)
    {
        fscanf(infileemp, "%d %d %d", &emp[i].tazid, &emp[i].basic,
            &emp[i].retail);
        fscanf(infileemp, "%d %d %d", &emp[i].service, &emp[i].gov,
            &emp[i].emptot);
    }

    /* output the employment data to a file or to the screen */
    for (i=0; i<=size; i++)
    {
        if (emp[i].tazid > 0)
        {
fprintf(outfileemp, "%d %d %d", emp[i].tazid, emp[i].basic, emp[i].retail);
fprintf(outfileemp, "%d %d %d
", emp[i].service, emp[i].gov, emp[i].emptot);
}
}

/* Read in travel time data.
Example:
infilett = 
fopen("/mit/qingshen2/ming/program/mfO8.hbw.utilout", "r");
outfilett = fopen("/mit/qingshen2/ming/program/mfO8.hbw.AvalueAll", "w"); */

printf("Enter input file with total travel time data file: ");
scanf("%s", infilettName);
if ((infilett = fopen(infilettName, "r")) == NULL) {
    printf("The file does not exist!
");
    exit(0);
}

printf("Enter output file name for accessibility value: ");
scanf("%s", outfilettName);

outfilett = fopen(outfilettName, "w");

while (fscanf(infilett, "%d", &A.FromTAZ) != EOF) {
    fscanf(infilett, "%d", &A.ToTAZ);
    fscanf(infilett, "%f", &A.ttime);

    j=0;
    while (A.ToTAZ != emp[j].tazid && j<size && A.ToTAZ <= size) {
        j++;
    }

    A.Ffactor = calcFriction(A.ttime);
    A.Abasic=A.Ffactor*emp[j].basic;
    A.Aretail=A.Ffactor*emp[j].retail;
    A.Aservice=A.Ffactor*emp[j].service;
    A.Agov=A.Ffactor*emp[j].gov;
    A.Avalue=A.Ffactor*emp[j].emptot;
    /* Computing accessibility index */

    /*fprintf(outfilett, "%d \t %d \t", A.FromTAZ, A.ToTAZ);
    fprintf(outfilett, "%s\t%8.3f\t%8.3f\t\n", A.ttime, A.Avalue);*/

    fprintf(outfilett, "%d %8.3f %8.3f %8.3f\n", A.FromTAZ, A.Abasic, A.Aretail);
    fprintf(outfilett, "%8.3f %8.3f %8.3f\n", A.Aservice, A.Agov, A.Avalue);
}
fclose (infileemp);
fclose (outfileemp);
fclose (infilett);
fclose (outfilett);
float calcFriction(float y) /*friction function based on travel time */
{
#define a 1
    /*In the original model the value of 'a' is 4106986. Since
    accessibility value is ordinal. Setting it to 1 will not affect the
    result. */
#define b -1.3924
#define c -0.0132
    float result=0;
    if (y == 0)
        {result = 0;}
    else if (y<0.99)
        {result = 1;}
    else
        {
        result = a*(exp(b*log(y)))*(exp(c*y));
        }
    return (result);
}

Code #2:

/***************************
calcAsum.c
***************************

File Name: calcAsum.c
Purpose: Calculate the aggregate accessibility index for each TAZ.
Date Created: 03-29-97
Created by: Ming Zhang
Date Modified:
Modified by:

Remarks: The input file is the output file of running calcAccess.c

*************************************************************************/
#include <stdio.h>
main()
{
    FILE *infileAcc, *outfileAcc;

    int tmpFTAZ, FromTAZ;
    float tmpAbasicScore, AbasicScore;
    float tmpAretailScore, AretailScore;
    float tmpAserviceScore, AserviceScore;
    float tmpAgovScore, AgovScore;
    float tmpAscore, Ascore;

    char infilename[25], outfilename[25];

    tmpAbasicScore=0;
    AbasicScore=0;
    tmpAretailScore=0;
AretailScore = 0;
tmpAserviceScore = 0;
AserviceScore = 0;
tmpAgovScore = 0;
AgovScore = 0;
tmpAscore = 0;
Ascore = 0;

/* Read in Access Value data. 
Example:
infileAcc = fopen("/mit/qingshen2/ming/program/mf08.hbw.AvalueAll", "r");
outfileAcc = fopen("/mit/qingshen2/ming/program/AUIVAccIDX.all", "w"); */

printf("Enter the name of the input Avalue file: ");
scanf("%s", infilename);
if ((infileAcc = fopen(infilename, "r")) == NULL)
{
    printf("The file does not exist!\n");
    exit(0);
}

printf("Name the output file with zonal accessibility index: ");
scanf("%s", outfilename);
outfileAcc = fopen(outfilename, "w");
fscanf(infileAcc, "%d", &FromTAZ);
rewind(infileAcc); /*reset position pointer to the beginning*/
while (!feof(infileAcc))
{
    fscanf(infileAcc, "%d %f %f", &tmpFTAZ, &tmpAbasicScore, &tmpAretailScore);
    fscanf(infileAcc, "%f %f %f", &tmpAserviceScore, &tmpAgovScore, &tmpAscore);
    if ((tmpFTAZ == FromTAZ) && (!feof(infileAcc)))
    {
        AbasicScore = AbasicScore + tmpAbasicScore;
        AretailScore = AretailScore + tmpAretailScore;
        AserviceScore = AserviceScore + tmpAserviceScore;
        AgovScore = AgovScore + tmpAgovScore;
        Ascore = Ascore + tmpAscore;
    }
    else
    {
        fprintf(outfileAcc, "%d,%.3f,%.3f, ", FromTAZ, AbasicScore, AretailScore);
        fprintf(outfileAcc, ".3f,%.3f,%.3f\n", AserviceScore, AgovScore, Ascore);

        FromTAZ = tmpFTAZ;
        AbasicScore = tmpAbasicScore;
        AretailScore = tmpAretailScore;
        AserviceScore = tmpAserviceScore;
        AgovScore = tmpAgovScore;
        Ascore = tmpAscore;
    }
}
fclose (infileAcc);
fclose (outfileAcc);
}

**Code #3:**

```c
#include <stdio.h>
define TAZs 768

main ()
{
    FILE *inputfile1, *inputfile2, *ivttovtt;
    int tmpFromTAZ, tmpToTAZ, i, j;
    float tmpTime;
    char infile1name[25], infile2name[25], ivttovttname[25];

    float ivtt[TAZs][TAZs], ovtt[TAZs][TAZs], alltt[TAZs][TAZs];

    for (i=1; i<TAZs; i++)
    {
        for (j=1; j<TAZs; j++)
        {
            ivtt[i][j]=0;
            ovtt[i][j]=0;
            alltt[i][j]=0;
        }
    }

    printf("Enter the name of the ivtt data file: ");
    scanf ("%s", infile1name);

    if ((inputfile1 = fopen(infile1name, "r")) == NULL)
    {
        printf("The file does not exist!\n");
        exit(0);
    }

    printf("Enter the name of the ovtt data file: ");
    scanf ("%s", infile2name);

    if ((inputfile2 = fopen(infile2name, "r")) == NULL)
    {
        printf("The file does not exist!\n");
    }

    printf("Enter the name of the ivtt data file: ");
    scanf ("%s", ivttovttname);

    if ((inputfile1 = fopen(ivttovttname, "r")) == NULL)
    {
        printf("The file does not exist!\n");
    }
```

File Name: MinTottMode.c
Purpose: Compare the total travel time of all transit modes and select the minimum as the total travel time of public transportation
Date Created: 01-2-98
Created by: Ming Zhang
Date Modified: 
Modified by: 
Remarks:
The input data files are in the layout format produced by RUNutilitySkipHeader
printf("Enter the name of the output MinTott file: ");
scanf ("%s", ivttovttname);

ivttovtt = fopen(ivttovttname, "w");

while (!feof(inputfile1))
{
    fscanf(inputfile1, "%d %d %f", &tmpFromTAZ, &tmpToTAZ, &tmpTime);
    if ((tmpFromTAZ < TAZs) && (tmpToTAZ < TAZs))
    {
        ivtt[tmpFromTAZ][tmpToTAZ] = tmpTime;
    }
}

while (!feof(inputfile2))
{
    fscanf(inputfile2, "%d %d %f", &tmpFromTAZ, &tmpToTAZ, &tmpTime);
    if ((tmpFromTAZ < TAZs) && (tmpToTAZ < TAZs))
    {
        ovtt[tmpFromTAZ][tmpToTAZ] = tmpTime;
    }
}

for (i=1; i<TAZs; i++)
{
    for (j=1; j<TAZs; j++)
    {
        alltt[i][j] = ivtt[i][j];
        if (ivtt[i][j] > ovtt[i][j])
        {
            alltt[i][j] = ovtt[i][j];
        }
        /* choose the smaller one (shorter travel time). */
        fprintf(ivttovtt, "%d\t", i);
        fprintf(ivttovtt, "%d\t", j);
        fprintf(ivttovtt, "%8.3f\n", alltt[i][j]);
    }
}
fclose (inputfile1);
fclose (inputfile2);
fclose (ivttovtt);

Code #4:

********************************** TripGenerate.c **********************************
File Name: TripGenerate.c
Purpose: Produce total zonal trip production and attraction tables
Date Created: 01-02-98
Created by: Ming Zhang
Date Modified:
Modified by:
Remarks:
The input data file is in the format produced by utility.c

#include <stdio.h>
#define TAZs 768

main ( )
{
    FILE *inputfile, *outAttfile, *outProfile;
    int tmpFromTAZ, tmpToTAZ, i, j;
    float tmpTrip, TripAtt, TripPro;
    char infilename[25], outAttname[25], outProname[25];
    float matrix[TAZs][TAZs];

    for (i=1; i<TAZs; i++)
    {
        for (j=1; j<TAZs; j++)
        {
            matrix[i][j]=0;
        }
    }

    printf("Enter the name of the input data file: ");
    scanf ("%s", infilename);

    if ((inputfile = fopen(infilename, "r")) == NULL)
    {
        printf("The file does not exist!\n");
        exit(0);
    }

    printf("Enter the name of the output trip attraction file: ");
    scanf ("%s", outAttname);

    outAttfile = fopen(outAttname, "w");

    printf("Enter the name of the output trip production file: ");
    scanf ("%s", outProname);

    outProfile = fopen(outProname, "w");

    while (!feof(inputfile))
    {
        fscanf(inputfile, "%d %d %f", &tmpFromTAZ, &tmpToTAZ, &tmpTrip);
        if ((tmpFromTAZ < TAZs) && (tmpToTAZ < TAZs))
        {
            matrix[tmpFromTAZ][tmpToTAZ] = tmpTrip;
        }
    }

    for (j=1; j<TAZs; j++)
    {
        TripAtt = 0;
        for (i=1; i<TAZs; i++)
        {
            TripAtt = TripAtt + matrix[i][j];
        }
        fprintf(outAttfile, "%d\t%8.3f\n", j, TripAtt);
for (i=1; i<TAZs; i++)
{
    TripPro = 0;
    for (j=1; j<TAZs; j++)
    {
        TripPro = TripPro + matrix[i][j];
    }
    fprintf(outProfile, "%d\t%8.3f\n", i, TripPro);
}

fclose (inputfile);
fclose (outAttfile);
fclose (outProfile);

Code #5:

#include <stdio.h>
#define fields 13
#define id_length 21

main ( )
{
    FILE *inputfile, *outfile;
    int i, field[fields];

    char bg90[id_length];
    char infilename[25], outfilename[25];

    printf("Enter the name of the input data file: ");
    scanf("%s", infilename);
    if ((inputfile = fopen(infilename, "r")] == NULL)
    {
        printf("The file does not exist!\n");
        exit(0);
    }
printf("Enter the name of the output file: ");
scanf("%s", outfile);

outfile = fopen(outfile, "w");

while (!feof(inputfile))
{
    for (i=0; i < id_length; i++)
    {
        fscanf(inputfile, "%c", &bg90[i]);
        if (bg90[i] == ' ')
        {
            bg90[i] = '0';
        }
    }
    for (i=0; i < fields; i++)
    {
        fscanf(inputfile, "%d", &field[i]);
    }
    fscanf(inputfile, "\n");
    /* output */
    for (i=5; i < 15; i++)
    {
        fprintf(outfile, "%c", bg90[i]);
    }
    for (i=0; i < fields; i++)
    {
        fprintf(outfile, ",%d", field[i]);
    }
    fprintf(outfile, "\n");
}
fclose (inputfile);
fclose (outfile);
}

Code #6

/******************** WeibullShenAccessModel.c ********************
File Name: WeibullShenAccessModel.c
Purpose: Calculate accessibility index for each TAZ using Weibull/Shen Model.
Date Created: 08-14-97
Created by: Ming Zhang
Date Modified:
Modified by:
Remarks:
To run this program on Athena,
add gcc
  gcc -ansi -lm -o A.outName CodeName

Three input files are needed and should be in appropriate layout as shown in the following example:
1). Travel Time O-D table by Auto
Example:

From TAZ To TAZ Travel Time
1 1 10
1 2 20
1 3 100
2 1 20
2 2 10
2 3 100
3 1 100
3 2 100
3 3 10

2). Travel Time O-D table by Transit

Example:

From TAZ To TAZ Travel Time
1 1 20
1 2 40
1 3 200
2 1 40
2 2 20
2 3 200
3 1 200
3 2 200
3 3 20

3). Socioeconomic data by TAZ

Example:

<table>
<thead>
<tr>
<th>TAZ</th>
<th>Workers %_with_Auto</th>
<th>%_TeleWorker</th>
<th>Jobs %_TeleJobs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unemployment</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>50000</td>
<td>0.5</td>
<td>0.4</td>
</tr>
<tr>
<td>2</td>
<td>150000</td>
<td>0.8</td>
<td>0.6</td>
</tr>
<tr>
<td>3</td>
<td>10000</td>
<td>0.9</td>
<td>0.5</td>
</tr>
</tbody>
</table>

***************

#include <stdio.h>
#include <stdlib.h>
#include <math.h>
#include <malloc.h>
#include <string.h>

#define size 788
#define NotTeleRatio 0.4

double exp (double x);
float calcFriction (float);

struct SocioEconoData
{
    int TAZid;
    int NumWorkers;
    float RateAuto;
    float RateTeleWorkers;
}
int NumJobs;
float RateTeleJobs;
int Unemp;
} SocioEcono[size];

main ( )
{
    /*********** Variables ***********/
    int tmpTAZid;
    int i, j,
    int tmpFromTAZ, tmpToTAZ;

    float y, tmpTime, AllDemand;
    float AllAutoTeleAcc, AllAutoNoTeleAcc, AllTransitTeleAcc,
         AllTransitNoTeleAcc;
    float TeleAutoTime, TeleTransitTime;
    float **AutoTime;
    float **TransitTime;
    float **tmpDemand;
    float **tmpAutoNoTeleAcc;
    float **tmpAutoTeleAcc;
    float **tmpTransitNoTeleAcc;
    float **tmpTransitTeleAcc;
    float *NoTeleDemand;
    float *TeleDemand;
    float *AccAutoNoTele;
    float *AccAutoTele;
    float *AccGeneral;
    float *AccTransitNoTele;
    float *AccTransitTele;

    char inAutoName[20], inTransitName[20], inSocioEconoName[20],
        outAccIDXName[20];

    /*********** Allocate memory ***********/
    AutoTime = (float**) calloc(size, sizeof(float*));
    if (AutoTime == NULL)
    {
        printf("\nRun out of memory! \n");
        exit(1);
    }
    for (i=1; i<=size; i++)
    {
        AutoTime[i] = (float*) calloc(size, sizeof(float));
    }

    TransitTime = (float**) calloc(size, sizeof(float*));
    if (TransitTime == NULL)
    {

    

}
printf("\nRun out of memory! \n");
exit(1);
}
for (i=1; i<=size; i++)
{
    TransitTime[i] = (float*) calloc(size, sizeof(float));
}

tmpDemand = (float**) calloc(size, sizeof(float*));
if (tmpDemand == NULL)
{
    printf("\nRun out of memory! \n");
    exit(1);
}
for (i=1; i<=size; i++)
{
    tmpDemand[i] = (float*) calloc(size, sizeof(float));
}

tmpAutoNoTeleAcc = (float**) calloc(size, sizeof(float*));
if (tmpAutoNoTeleAcc == NULL)
{
    printf("\nRun out of memory! \n");
    exit(1);
}
for (i=1; i<=size; i++)
{
    tmpAutoNoTeleAcc[i] = (float*) calloc(size, sizeof(float));
}

tmpAutoTeleAcc = (float**) calloc(size, sizeof(float*));
if (tmpAutoTeleAcc == NULL)
{
    printf("\nRun out of memory! \n");
    exit(1);
}
for (i=1; i<=size; i++)
{
    tmpAutoTeleAcc[i] = (float*) calloc(size, sizeof(float));
}

tmpTransitNoTeleAcc = (float**) calloc(size, sizeof(float*));
if (tmpTransitNoTeleAcc == NULL)
{
    printf("\nRun out of memory! \n");
    exit(1);
}
for (i=1; i<=size; i++)
{
    tmpTransitNoTeleAcc[i] = (float*) calloc(size, sizeof(float));
}

tmpTransitTeleAcc = (float**) calloc(size, sizeof(float*));
if (tmpTransitTeleAcc == NULL)
{
    printf("\nRun out of memory! \n");
}
exit(1);

for (i=1; i<=size; i++)
{
    tmpTransitTeleAcc[i] = (float*) calloc(size, sizeof(float));
}

NoTeleDemand = (float*) calloc(size, sizeof(float));
TeleDemand = (float*) calloc(size, sizeof(float));
AccAutoNoTele = (float*) calloc(size, sizeof(float));
AccAutoTele = (float*) calloc(size, sizeof(float));
AccGeneral = (float*) calloc(size, sizeof(float));
AccTransitNoTele = (float*) calloc(size, sizeof(float));
AccTransitTele = (float*) calloc(size, sizeof(float));

//************ Initialize the variables ************/

AllAutoNoTeleAcc=0;
AllAutoTeleAcc=0;
AllTransitNoTeleAcc=0;
AllTransitTeleAcc=0;

for (i=1; i<size; i++)
{
    NoTeleDemand[i]=0;
    TeleDemand[i] =0;
    AccAutoNoTele[i]=0;
    AccAutoTele[i]=0;
    AccTransitNoTele[i]=0;
    AccTransitTele[i]=0;
    AccGeneral[i]=0;

    for (j=1; j<size; j++)
    {
        AutoTime[i][j]=0;

        /* Specify intrazonal auto travel time which is missing in the data
file*/
        if (i == j)
            {AutoTime[i][j]=5;
        }
        TransitTime[i][j]=0;
        tmpDemand[i][j]=0;
        tmpAutoNoTeleAcc[i][j]=0;
        tmpAutoTeleAcc[i][j]=0;
        tmpTransitNoTeleAcc[i][j]=0;
        tmpTransitTeleAcc[i][j]=0;
        }
    }

//************ Read in auto travel time data. ************/

printf("Enter the name of the file with AUTO travel time: ");
scanf("%s", inAutoName);

if ((inAutoTime = fopen(inAutoName, "r")) == NULL)
{
    printf("The file does not exist!
");
    exit(0);
}
/*********** Read in transit travel time data. ***********/
printf("Enter the name of the file with TRANSIT travel time: ");
scanf("%s", inTransitName);

if ((inTransitTime = fopen(inTransitName, "r").)) == NULL)
  {
    printf("The file does not exist!\n");
    exit(0);
  }

/*********** Read in socioeconomic data. ***********/
printf("Enter the name of the file with the socioeconomic data: ");
scanf("%s", inSocioEconoName);

if ((inSocioEcono = fopen(inSocioEconoName, "r").)) == NULL)
  {
    printf("The file does not exist!\n");
    exit(0);
  }

/*********** Specify output file name ***********/
printf("Enter the name of the output file: ");
scanf("%s", outAccIDXName);

outAccIDX = fopen(outAccIDXName, "w");

while (((fscanf(inAutoTime, "%d", &tmpFromTAZ).) != EOF) \
    && (tmpFromTAZ < size))
  {
    fscanf(inAutoTime, "%d %f", &tmpToTAZ, &tmpTime);
    if (tmpToTAZ < size)
    {
        AutoTime[tmpFromTAZ][tmpToTAZ] = tmpTime;
    }
  }

while (((fscanf(inTransitTime, "%d", &tmpFromTAZ).) != EOF) \
    && (tmpFromTAZ < size))
  {
    fscanf(inTransitTime, "%d %f", &tmpToTAZ, &tmpTime);
    if (tmpToTAZ < size)
    {
        TransitTime[tmpFromTAZ][tmpToTAZ] = tmpTime;
    }
  }

while (((fscanf(inSocioEcono, "%d", &tmpTAZid).) != EOF) \
    && (tmpTAZid < size))
  {
    SocioEcono[tmpTAZid].TAZid = tmpTAZid;
    fscanf(inSocioEcono, "%d", &SocioEcono[tmpTAZid].NumWorkers);
    fscanf(inSocioEcono, "%f", &SocioEcono[tmpTAZid].RateAuto);
    fscanf(inSocioEcono, "%f", &SocioEcono[tmpTAZid].RateTeleWorkers);

138
```c
fscanf(inSocioEcono, "%d", &SocioEcono[tmpTAZid].NumJobs);
fscanf(inSocioEcono, "%f", &SocioEcono[tmpTAZid].RateTeleJobs);
fscanf(inSocioEcono, "%d", &SocioEcono[tmpTAZid].Unemp);
}

/******* Computing No_Telecom demand potential *******/
for (i=1; i<size; i++)
{
    for (j=1; j<size; j++)
    {
        tmpDemand[j][i] = calcFriction(AutoTime[j][i]) \ 
            * (SocioEcono[j].NumWorkers + SocioEcono[j].Unemp) \ 
            * SocioEcono[j].RateAuto + calcFriction(TransitTime[j][i]) \ 
            * (SocioEcono[j].NumWorkers + SocioEcono[j].Unemp) \ 
            * (1-SocioEcono[j].RateAuto);
    }
}

for (i=1; i<size; i++)
{
    for (j=1; j<size; j++)
    {
        AllDemand = AllDemand + tmpDemand[j][i];
    }
    NoTeleDemand[i] = AllDemand;
    AllDemand = 0;
}

/******* Computing With_Telecom demand potential *******/
for (i=1; i<size; i++)
{
    for (j=1; j<size; j++)
    {
        TeleAutoTime=NotTeleRatio*AutoTime[j][i];
        TeleTransitTime=NotTeleRatio*TransitTime[j][i];
        tmpDemand[j][i] = calcFriction(TeleAutoTime) \ 
            * (SocioEcono[j].NumWorkers+ SocioEcono[j].Unemp) \ 
            * SocioEcono[j].RateTeleWorkers * SocioEcono[j].RateAuto \ 
            + calcFriction(TeleTransitTime) \ 
            * SocioEcono[j].RateTeleWorkers \ 
            * (SocioEcono[j].NumWorkers+ SocioEcono[j].Unemp) \ 
            * (1-SocioEcono[j].RateAuto);
    }
}

AllDemand = 0;
for (i=1; i<size; i++)
{
    for (j=1; j<size; j++)
    {
        AllDemand = AllDemand + tmpDemand[j][i];
    }
    TeleDemand[i] = AllDemand;
    AllDemand = 0;
}
```
for (i=1; i<size; i++)
{
    for (j=1; j<size; j++)
    {
        if (NoTeleDemand[j]>0)
        {
            tmpAutoNoTeleAcc[i][j] = calcFriction(AutoTime[i][j]) \ 
                * SocioEcono[j].NumJobs \ 
                * (1-SocioEcono[j].RateTeleJobs)/NoTeleDemand[j];
            tmpTransitNoTeleAcc[i][j] = calcFriction(TransitTime[i][j])\ 
                * SocioEcono[j].NumJobs \ 
                * (1-SocioEcono[j].RateTeleJobs)/NoTeleDemand[j];

            TeleAutoTime=NotTeleRatio*AutoTime[i][j];
            TeleTransitTime=NotTeleRatio*TransitTime[i][j];

            if (TeleDemand[j]>0)
            {
                tmpAutoTeleAcc[i][j] = calcFriction(TeleAutoTime) \ 
                    * SocioEcono[j].NumJobs \ 
                    * SocioEcono[j].RateTeleJobs/TeleDemand[j] \ 
                    + tmpAutoNoTeleAcc[i][j];
                tmpTransitTeleAcc[i][j] = calcFriction(TeleTransitTime) \ 
                    * SocioEcono[j].NumJobs \ 
                    * SocioEcono[j].RateTeleJobs/TeleDemand[j] \ 
                    + tmpTransitNoTeleAcc[i][j];
            }
        }
    }
}

for (i=1; i<size; i++)
{
    for (j=1; j<size; j++)
    {
        if(SocioEcono[i].TAZid>0)
        {
            AllAutoNoTeleAcc = AllAutoNoTeleAcc +
            tmpAutoNoTeleAcc[i][j];
            AllAutoTeleAcc = AllAutoTeleAcc + tmpAutoTeleAcc[i][j];
            AllTransitNoTeleAcc = AllTransitNoTeleAcc \ 
                + tmpTransitNoTeleAcc[i][j];
            AllTransitTeleAcc = AllTransitTeleAcc +
            tmpTransitTeleAcc[i][j];
        }
    }
}

AccAutoNoTele[i] = AllAutoNoTeleAcc;
AccAutoTele[i] = AllAutoTeleAcc;
AccTransitNoTele[i] = AllTransitNoTeleAcc;
AccTransitTele[i] = AllTransitTeleAcc;

AccGeneral[i] = AccAutoTele[i]\ 
    *SocioEcono[i].RateAuto*SocioEcono[i].RateTeleWorkers \ 
    + AccAutoNoTele[i]*SocioEcono[i].RateAuto \ 
    * (1-SocioEcono[i].RateTeleWorkers) + AccTransitTele[i] \ 
    *(1-SocioEcono[i].RateAuto)*SocioEcono[i].RateTeleWorkers \ 
    + AccTransitNoTele[i]*(1-SocioEcono[i].RateAuto) \ 
    *(1-SocioEcono[i].RateTeleWorkers);
AllAutoNoTeleAcc=0;
AllAutoTeleAcc=0;
AllTransitNoTeleAcc=0;
AllTransitTeleAcc=0;
}

fprintf(outAccIDX, "TAZ AccAutoNoTele AccAutoTele AccTransitNoTele \ 
AccTransitTele GeneralAcc")

for (i=1; i<size; i++)
{
    fprintf(outAccIDX, "%d \t %8.3f \t", i, AccAutoNoTele[i]);
    fprintf(outAccIDX, "%8.3f \t", AccAutoTele[i]);
    fprintf(outAccIDX, "%8.3f\t", AccTransitNoTele[i]);
    fprintf(outAccIDX, "%8.3f\t", AccTransitTele[i]);
    fprintf(outAccIDX, "%8.3f\n", AccGeneral[i]);
}

fclose (inAutoTime);
fclose (inTransitTime);
fclose (inSocioEcono);
fclose (outAccIDX);

float calcFriction (float y) /*friction function based on travel time */
{

    #define b -0.1034

    float result=0;
    if (y == 0)
    {
        result = 0;
    }
    else if (y<0.99)
    {
        result = 1;
    }
    else
    {
        result = exp(b*y);
    }
    return (result);
}
Appendix B:

Data Inventory

This appendix contains the data sets used for the research project. Some data sets such as non-home-based work trip data are available per request. They have been collected but not included in this appendix because they were not directly used for this research.

- **TRIP DATA**

(Source: CambridgeSystematics, Inc. 150 CambridgePark Drive, Suite 4000 Cambridge, MA 02140)

For all of the 1990 Base, 2010 Tren Urbano Build and Tren Urbano No-Build cases unless specified.

**PERSON TRIPS**

- HBW-SOV Auto, single occupant
- HBW-HOV2 Auto, two occupants
- HBW-HOV3 Auto, three or more occupants
- HBW-MD Bus, drive access
- HBW-MW Bus, walk access
- HBW-PD Publico, drive access
- HBW-PW Publico, walk access

**TRIP TIME**

Auto

AUTOTT.HWB

Bus (drive access)

MDAUX.HWB access time
MDIVTT.HWB in-vehicle time
MDWAIT.HWB wait time

Bus (walk access)

MWAUX.HWB access time
MWIVTT.HWB in-vehicle time
MWWAIT.HWB wait time

Publico (drive access)

PDAUX.HWB access time
PDIVTT.HWB in-vehicle time
PDWAIT.HWB wait time

Publico (walk access)

142
PWAUX.HWB access time
PWIVTT.HWB in-vehicle time
PWWAIT.HWB wait time

Rail (drive access)

PDAUX.HWB access time
PDIVTT.HWB in-vehicle time
PDWAIT.HWB wait time

Rail (walk access)

PWAUX.HWB access time
PWIVTT.HWB in-vehicle time
PWWAIT.HWB wait time

TRIP COSTS

AUTOTOLL auto
MDFARE bus, drive access
MWFARE bus, walk access
PDFARE Publico, drive access
PWFARE Publico, walk access
RDFARE rail, drive access
RWFARE rail, walk access

TRIP DISTANCE

AUTODISTANCE.HBW

• GEOGRAPHIC DATA

(Source: Processed from Census TIGER/Line Files, 1992, by author unless specified.)

All in ArcInfo format except TAZ.

Note: The San Juan Metropolitan Region (SJMR) consists of the following municipalities. The SJMR-level coverage was obtained by processing each of the municipalities and then combined them. Due to the storage space constraint, all of the coverage for individual municipalities has been deleted. But they can be generated from the SJMR coverage without going through TIGER File processing procedure.

<table>
<thead>
<tr>
<th>Code</th>
<th>County</th>
</tr>
</thead>
<tbody>
<tr>
<td>021</td>
<td>Bayamon</td>
</tr>
<tr>
<td>029</td>
<td>Canovanos</td>
</tr>
<tr>
<td>031</td>
<td>Carolina</td>
</tr>
<tr>
<td>033</td>
<td>Catano</td>
</tr>
<tr>
<td>051</td>
<td>Dorado</td>
</tr>
<tr>
<td>061</td>
<td>Guaynabo</td>
</tr>
<tr>
<td>087</td>
<td>Loiza</td>
</tr>
<tr>
<td>105</td>
<td>Naranjito</td>
</tr>
<tr>
<td>119</td>
<td>Rio Grande</td>
</tr>
<tr>
<td>127</td>
<td>San Juan</td>
</tr>
<tr>
<td>135</td>
<td>Toa Alta</td>
</tr>
<tr>
<td>137</td>
<td>Toa Baja</td>
</tr>
</tbody>
</table>
SJMRCNTY  municipality boundary
TAZ  TAZ boundary for the SJMR, obtained from the Tren Urbano Office, San Juan, Puerto Rico. Attributes include population and employment in 1990 and 2010 and land use in 1990. PC ArcInfo format. Unknown projection.
TAZTICA2  Same as TAZ but registered in Longitude/Latitude system
BGSJMA  Census Blockgroup coverage
BGTAZSJMA  overlay of Blockgroup and TAZ
STRSJMA  street network
STRBGSJMA  overlay of Blockgroup and street network
TGRSJMA  TIGER/Line Files for the SJMR
TUSTATION  proposed Tren Urbano station locations
TUSSTR5MIN  5 minutes walking distance buffer from stations
TU1320FTBUF  quarter-mile buffer from stations
TU2640FTBUF  half-mile buffer from stations

• CENSUS STF3A, 1990
(Census STF3A for the SJMR only)
BGTAJ90FACTOR  a cross-referring table linking TAZ-level with Blockgroup-level information. Created by author.

STF304PR.DAT
STF305PR.DAT
STF311PR.DAT
STF312PR.DAT
STF314PR.DAT
STF315PR.DAT
STF316PR.DAT
STF317PR.DAT