Impacts Of Light Rail

In Job Accessibility In Phoenix

by

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A Thesis Presented in Partial Fulfillment
of the Requirements for the Degree
Master of Urban and Environmental Planning

Approved April 2014 by the
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May 2014
ABSTRACT

It has been identified in the literature that there exists a “spatial mismatch” between geographical concentrations of lower-income or minority people who have relatively lower rates of car ownership, lower skills or educational attainment and who mainly rely on public transit for their travel, and low-skilled jobs for which they more easily qualify. Given this situation, various types of transportation projects have been constructed to improve public transit services and, alongside other goals, improve the connection between low-skilled workers and jobs. As indicators of performance, measures of job accessability are commonly used to gauge how such improvements have facilitated job access. Following this approach, this study investigates the impact of the Phoenix Metro Light Rail on job accessibility for the transit users, by calculating job accessibility before and after the opening of the system. Moreover, it also investigates the demographic profile of those who have benefited from improvements in job accessibility—both by income and by ethnicity. Job accessibility is measured using the cumulative opportunity approach which quantifies the job accessibility within different travel time limits, such as 30 and 45 minutes. ArcGIS is used for data processing and results visualization. Results show that the Phoenix light rail has improved job accessibility of the traffic analysis zones that are along the light rail line and Hispanic and lower-income groups have benefited more than their counterparts.
# TABLE OF CONTENTS

| LIST OF TABLES | V |
| LIST OF FIGURES | VI |

Introduction ........................................................................................................................................ 1

Motivation .......................................................................................................................................... 1

Transportation Problems .................................................................................................................... 4

Spatial mismatch .................................................................................................................................. 7

Background of spatial mismatch .......................................................................................................... 8

The debate ............................................................................................................................................ 11

Civil Rights and Transportation Policies ............................................................................................ 12

Plan for thesis ....................................................................................................................................... 15

Literature Review ................................................................................................................................. 16

Previous work on disparities in job accessibility .................................................................................. 16

Definitions of accessibility. .................................................................................................................... 16

Accessibility as a performance indicator ............................................................................................... 17

Job accessibility and spatial mismatch ................................................................................................. 19

Measures of Accessibility ...................................................................................................................... 21

Infrastructure-based accessibility measures. .......................................................................................... 23
Location-based accessibility measures ................................................................. 24
Person-based accessibility measures ............................................................... 26
Utility-based accessibility measures ............................................................... 26
Case Study ........................................................................................................ 28
Background of Study Area .............................................................................. 28
Phoenix Metropolitan Area ............................................................................ 29
City of Phoenix and Metro Light Rail .............................................................. 31
Methods ........................................................................................................... 34
Accessibility Calculation Structure ................................................................. 34
Data Requirements .......................................................................................... 39
Results ............................................................................................................. 40
Mapping Demographics .................................................................................. 40
General demographics .................................................................................... 42
Ethnicity demographics ................................................................................... 48
Economic demographics .................................................................................. 53
Mapping Analysis ............................................................................................ 59
45 minutes, walking, base maps of accessibility (non-light rail) ....................... 62
Differences in access ....................................................................................... 70
Percent change of accessibility ...................................................................... 76
# LIST OF TABLES

<table>
<thead>
<tr>
<th>Table</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Walking, 30 minutes, Non-LRT</td>
<td>184</td>
</tr>
<tr>
<td>2. Walking, 30 minutes, Difference in Accessibility</td>
<td>184</td>
</tr>
<tr>
<td>3. Walking, 30 minutes, Percent Change in Accessibility</td>
<td>185</td>
</tr>
<tr>
<td>4. Walking, 45 minutes, Non-LRT</td>
<td>185</td>
</tr>
<tr>
<td>5. Walking, 45 minutes, Difference in Accessibility</td>
<td>186</td>
</tr>
<tr>
<td>6. Walking, 45 minutes, Percent Change in Accessibility</td>
<td>186</td>
</tr>
</tbody>
</table>
# LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Map of Phoenix Metropolitan Area</td>
<td>28</td>
</tr>
<tr>
<td>2. Phoenix Metro Light Rail System Map</td>
<td>32</td>
</tr>
<tr>
<td>3. Average Daily Ridership of Phoenix Light Rail, 2010—2012</td>
<td>33</td>
</tr>
<tr>
<td>4. Total Monthly Ridership of Phoenix Light Rail, 2010—2012</td>
<td>34</td>
</tr>
<tr>
<td>5. Methodology Diagram of Job Accessibility Calculation</td>
<td>37</td>
</tr>
<tr>
<td>6. All TAZs General Demographics, 2008. Total Population</td>
<td>42</td>
</tr>
<tr>
<td>7. All TAZs General Demographics, 2008. Total Employment</td>
<td>43</td>
</tr>
<tr>
<td>8. All TAZs General Demographics, 2008. Total Households</td>
<td>44</td>
</tr>
<tr>
<td>9. All TAZs General Demographics, 2008. Single Family Households</td>
<td>45</td>
</tr>
<tr>
<td>10. All TAZs General Demographics, 2008. Multi-family households</td>
<td>46</td>
</tr>
<tr>
<td>11. All TAZs Ethnic Demographics. Race and Hispanic or Latino Origin—One Race</td>
<td>48</td>
</tr>
<tr>
<td>12. All TAZs Ethnic Demographics. Race and Hispanic or Latino Origin—One Race, White</td>
<td>49</td>
</tr>
<tr>
<td>13. All TAZs Ethnic Demographics. Race and Hispanic or Latino Origin—One Race, Black or African American</td>
<td>50</td>
</tr>
<tr>
<td>14. All TAZs Ethnic Demographics. White Alone, Not Hispanic or Latino</td>
<td>51</td>
</tr>
<tr>
<td>15. All TAZs Ethnic Demographics. Hispanic or Latino Origin (of any race)</td>
<td>52</td>
</tr>
<tr>
<td>16. All TAZs Employment Demographics, 2008. Public Employment</td>
<td>53</td>
</tr>
<tr>
<td>17. All TAZs Employment Demographics, 2008. Retail Employment</td>
<td>54</td>
</tr>
<tr>
<td>18. All TAZs Employment Demographics, 2008. Office Employment</td>
<td>55</td>
</tr>
<tr>
<td>19. All TAZs Employment Demographics, 2008. Industrial Employment</td>
<td>56</td>
</tr>
</tbody>
</table>
20. All TAZs Income Demographics, 2008. Lowest Income Quintile ..........................57
21. All TAZs Income Demographics, 2008. Low Income Quintile ..........................58
22. All TAZs Income Demographics, 2008. Lower Income Households .....................59
23. Organization of Maps—Walking .................................................................61
24. 45 Min, Walking, Non-LRT. Total Population Accessibility ..................................64
25. 45 Min, Walking, Non-LRT. Total Employment Accessibility ..............................65
26. 45 Min, Walking, Non-LRT. Public Employment Accessibility .............................66
27. 45 Min, Walking, Non-LRT. Retail Employment Accessibility .............................67
28. 45 Min, Walking, Non-LRT. Office Employment Accessibility .............................68
29. 45 Min, Walking, Non-LRT. Industrial Employment Accessibility .....................69
30. 45 Min, Walking, Difference. Total Population Accessibility ............................70
31. 45 Min, Walking, Difference. Total Employment Accessibility ............................71
32. 45 Min, Walking, Difference. Public Employment Accessibility ...........................72
33. 45 Min, Walking, Difference. Retail Employment Accessibility ...........................73
34. 45 Min, Walking, Difference. Office Employment Accessibility ...........................74
35. 45 Min, Walking, Difference. Industrial Employment Accessibility .....................75
36. 45 Min, Walking, Percent Change. Total Population Accessibility ........................76
37. 45 Min, Walking, Percent Change. Total Employment Accessibility .....................77
38. 45 Min, Walking, Percent Change. Public Employment Accessibility ....................78
39. 45 Min, Walking, Percent Change. Retail Employment Accessibility ....................79
40. 45 Min, Walking, Percent Change. Office Employment Accessibility ....................80
41. 45 Min, Walking, Percent Change. Industrial Employment Accessibility .............81
42. 45 Min, Walking, Non-LRT. Accessibility by race and income ............................83
43. 45 Min, Walking, Difference. Accessibility by race and income. .......................... 84
44. 45 Min, Walking, Percent Change (With-LRT). Accessibility by race and income... 85
45. Total Population Accessibility, Walking, 30 minutes, Non-Light Rail.................... 94
46. Total Employment Accessibility, Walking, 30 minutes, Non-Light Rail ................. 95
47. Public Employment Accessibility, Walking, 30 minutes, Non-Light Rail................ 96
48. Retail Employment Accessibility, Walking, 30 minutes, Non-Light Rail ............... 97
49. Office Employment Accessibility, Walking, 30 minutes, Non-Light Rail ............... 98
50. Industrial Employment Accessibility, Walking, 30 minutes, Non-Light Rail ......... 99
51. Difference in Total Population Accessibility, Walking, 30 minutes ..................... 100
52. Difference in Total Employment Accessibility, Walking, 30 minutes ................. 101
53. Difference in Public Employment Accessibility, Walking, 30 minutes ............... 102
54. Difference in Retail Employment Accessibility, Walking, 30 minutes ............... 103
55. Difference in Office Employment Accessibility, Walking, 30 minutes ............... 104
56. Difference in Industrial Employment Accessibility, Walking, 30 minutes ......... 105
57. Percent Change in Total Population Accessibility, Walking, 30 minutes ............. 106
58. Percent Change in Total Employment Accessibility, Walking, 30 minutes ......... 107
59. Percent Change in Public Employment Accessibility, Walking, 30 minutes ....... 108
60. Percent Change in Retail Employment Accessibility, Walking, 30 minutes ....... 109
61. Percent Change in Office Employment Accessibility, Walking, 30 minutes ...... 110
62. Percent Change in Industrial Employment Accessibility, Walking, 30 minutes ... 111
63. Total Population Accessibility, PNR, 30 minutes, Non-Light Rail .................... 112
64. Total Employment Accessibility, PNR, 30 minutes, Non-Light Rail ................... 113
65. Public Employment Accessibility, PNR, 30 min, Non-Light Rail...................... 114
66. Retail Employment Accessibility, PNR, 30 min, Non-LRT ........................................ 115
67. Office Employment Accessibility, PNR, 30 min, Non-LRT ........................................ 116
68. Industrial Employment Accessibility, PNR, 30 min, Non-LRT ........................................ 117
69. Difference in Total Population Accessibility, PNR, 30 min ........................................ 118
70. Difference in Total Employment Accessibility, PNR, 30 min ........................................ 119
71. Difference in Public Employment Accessibility, PNR, 30 min ........................................ 120
72. Difference in Retail Employment Accessibility, PNR, 30 min ........................................ 121
73. Difference in Office Employment Accessibility, PNR, 30 min ........................................ 122
74. Difference in Industrial Employment Accessibility, PNR, 30 min ........................................ 123
75. Percent Change in Total Population Accessibility, PNR, 30 min ........................................ 124
76. Percent Change in Total Employment Accessibility, PNR, 30 min ........................................ 125
77. Percent Change in Public Employment Accessibility, PNR, 30 min ........................................ 126
78. Percent Change in Retail Employment Accessibility, PNR, 30 min ........................................ 127
79. Percent Change in Office Employment Accessibility, PNR, 30 min ........................................ 128
80. Percent Change in Industrial Employment Accessibility, PNR, 30 min ........................................ 129
81. Total Population Accessibility, PNR, 45 min, Non-LRT .................................................. 130
82. Total Employment Accessibility, PNR, 45 min, Non-LRT .................................................. 131
83. Public Employment Accessibility, PNR, 45 min, Non-LRT .................................................. 132
84. Retail Employment Accessibility, PNR, 45 min, Non-LRT .................................................. 133
85. Office Employment Accessibility, PNR, 45 min, Non-LRT .................................................. 134
86. Industrial Employment Accessibility, PNR, 45 min, Non-LRT .................................................. 135
87. Difference in Total Population Accessibility, PNR, 45 min .................................................. 136
88. Difference in Total Employment Accessibility, PNR, 45 min .................................................. 137
89. Difference in Public Employment Accessibility, PNR, 45 min ...................... 138
90. Difference in Retail Employment Accessibility, PNR, 45 min .................. 139
91. Difference in Office Employment Accessibility, PNR, 45 min .............. 140
92. Difference in Industrial Employment Accessibility, PNR, 45 min .......... 141
93. Percent Change in Total Population Accessibility, PNR, 45 min .......... 142
94. Percent Change in Total Employment Accessibility, PNR, 45 min ........ 143
95. Percent Change in Public Employment Accessibility, PNR, 45 min .... 144
96. Percent Change in Retail Employment Accessibility, PNR, 45 min ...... 145
97. Percent Change in Office Employment Accessibility, PNR, 45 min ...... 146
98. Percent Change in Industrial Employment Accessibility, PNR, 45 min 147
99. Total Population Accessibility, KNR, 30 min, Non-LRT ..................... 148
100. Total Employment Accessibility, KNR, 30 min, Non-LRT ................... 149
101. Public Employment Accessibility, KNR, 30 min, Non-LRT ................. 150
102. Retail Employment Accessibility, KNR, 30 min, Non-LRT ................. 151
103. Office Employment Accessibility, KNR, 30 min, Non-LRT ............... 152
104. Industrial Employment Accessibility, KNR, 30 min, Non-LRT ........... 153
105. Difference in Total Population Accessibility, KNR, 30 min ............... 154
106. Difference in Total Employment Accessibility, KNR, 30 min .......... 155
107. Difference in Public Employment Accessibility, KNR, 30 min .......... 156
108. Difference in Retail Employment Accessibility, KNR, 30 min .......... 157
109. Difference in Office Employment Accessibility, KNR, 30 min .......... 158
110. Difference in Industrial Employment Accessibility, KNR, 30 min ....... 159
111. Percent Change in Total Population Accessibility, KNR, 30 min ......... 160
112. Percent Change in Total Employment Accessibility, KNR, 30 min ...............161
113. Percent Change in Public Employment Accessibility, KNR, 30 min ...............162
114. Percent Change in Retail Employment Accessibility, KNR, 30 min ...............163
115. Percent Change in Office Employment Accessibility, KNR, 30 min ...............164
116. Percent Change in Industrial Employment Accessibility, KNR, 30 min ...............165
117. Total Population Accessibility, KNR, 30 min, Non-LRT ........................................166
118. Total Employment Accessibility, KNR, 45 min, Non-LRT ........................................167
119. Public Employment Accessibility, KNR, 45 min, Non-LRT ........................................168
120. Retail Employment Accessibility, KNR, 45 min, Non-LRT ........................................169
121. Office Employment Accessibility, KNR, 45 min, Non-LRT ........................................170
122. Industrial Employment Accessibility, KNR, 45 min, Non-LRT .........................171
123. Difference in Total Population Accessibility, KNR, 45 min .........................172
124. Difference in Total Employment Accessibility, KNR, 45 min .........................173
125. Difference in Public Employment Accessibility, KNR, 45 min .........................174
126. Difference in Retail Employment Accessibility, KNR, 45 min .........................175
127. Difference in Office Employment Accessibility, KNR, 45 min .........................176
128. Difference in Industrial Employment Accessibility, KNR, 45 min .........................177
129. Percent Change in Total Population Accessibility, KNR, 45 min .........................178
130. Percent Change in Total Employment Accessibility, KNR, 45 min .........................179
131. Percent Change in Public Employment Accessibility, KNR, 45 min .........................180
132. Percent Change in Retail Employment Accessibility, KNR, 45 min .........................181
133. Percent Change in Office Employment Accessibility, KNR, 45 min .........................182
134. Percent Change in Industrial Employment Accessibility, KNR, 45 min .........................183
135. Accessibility by race and income, Walking, 30 min, Non-LRT .......................187
136. Difference in accessibility by race and income, Walking, 30 min .....................188
137. Percent change in accessibility by race and income, Walking, 30 min ............189
Motivation

Twenty years ago, Bruton, an academic transportation planner, stated, “Transportation inevitably influences the quality of life”, (Bruton, 1993). Transportation is one of the essential goods and service that people take advantage of in the everyday life. Transportation connects people and places, and the wide network of transportation shapes the interaction of the world. For example, transportation creates the ability to access all kinds of destinations, such as schools, hospitals, shops, and entertainment places, as an induced demand or ‘enabling accessibility function’. Not only that, even ‘odd exceptions’ (Lucas, 2004), such as joyriding or Sunday afternoon drives in the country side, prove that transportation in itself is important to people as an essential and luxury good that many enjoy.

Nevertheless, negative social and health costs of transportation have imposed heavy burdens on society. Some examples are air pollution from automobile emissions, congestion, safety issues, and social equity issues. However, Hill pointed out that the realm of social and public policy has omitted the topic of transportation in the comprehensive analysis of the welfare of the citizens (Hill, 1996). Similarly, in transportation planning, the main focus of activity has been geared towards ideal goals that are based on Cost Benefit Analysis (CBA), which can improve operating conditions for automobiles. This situation has resulted in a general tendency for transportation systems to favor physical movement rather than improving access to goods and services.
for the population as a whole including minority ethnic and low-income groups (Lucas, 2004).

The public is becoming more and more aware of these costs and the criticism of such planning methods has also become extensive and venerable. Legislation and state policies has made some progress in guiding the transportation planning process towards more comprehensive considerations from a systematical social science perspective. However, the transportation planning system has not been modified thoroughly and systematically.

Although there will never be a simple solution to the problems that are caused by the complex transportation system, transportation professionals continue to explore ways to mitigate the perceived issues. Results from current attempts to fix the issues are represented by the various transportation designs and social policies. On the design side, transportation Oriented Development (TOD), Bus Rapid Transit (BRT), and various road system designs are all good examples of transportation planning improvements. Recently, light rail transit (LRT) systems have also gained much attention in both developed and developing countries and it continues to be increasingly popular in middle sized cities. Light rail systems are built or approved to combat congestion, urban sprawl, and environmental pollution. Opponents question light rail’s ability to generate ridership in low-density, auto-oriented, polycentric U.S. cities with smaller downtowns. Gomez-ibanez has provided statistics to show that LRT systems cost more than the conventional bus service and that the costs per added rider are high (Jose A. Gomez-ibanez, 1985). On the contrary, proponents state that it is possible to have sufficient numbers of homes and workplaces that have convenient access to stations via walking, park-and-ride, or bus to
develop feasible corridors connecting major residential areas with suburban concentrations of employment as well as the Central Business District (CBD). Proponents also argue that LRT is not only less expensive to build than heavy rail or subway systems but that it also costs no more to operate than conventional bus transit and offers greatly improved service (Knowles, 1996; Kuby, Barranda, and Upchurch, 2004; Cervero, 1984; Fan, Guthrie, and Levinson, 2012; Pushkarev, Boris, and Zupan, 1980).

With that said, the goal of this paper is to find out whether the light rail system is helpful in mitigating the negative costs brought by current transportation system. A review of the literature on light rail transit shows that most studies focus on light rail impacts on land and property values (using hedonic price models); on urban development; and on light rail ridership studies. Very few studies place the foci on light rail’s social impact or social equity impact, such as light rail’s effect on employment comparing different racial and income groups. The social equity problem has created fierce discussion in transportation literatures. Examples include the debate between private vehicles and public transit in general, or the ‘spatial mismatch’ and ‘modal mismatch’ discussions. Unfortunately, the social equity issue has not been well studied in the light rail study area.

This study will look at light rail transit through a social equity perspective to investigate the impact of the Phoenix Metro Light Rail on job accessibility by calculating job accessibility before and after the opening of the LRT system. Moreover, it will investigate the demographic profile of those who have benefited from the improvements in job accessibility if they are found—both by income and by ethnicity. Job accessibility will be measured using the cumulative opportunity approach which quantifies the job
accessibility of each traffic analysis zone (TAZ) in the Phoenix Metro Area. Two travel
time limits of 30 and 45 minutes were used to generate different accessible areas of each
TAZ. Mode choices from home to public transit stations and bus stops will be
incorporated into travel time calculation, something which is not regularly done in
previous work (Kim, Ulfarsson, Hennessy, 2007). This is the only study that focuses on
the Phoenix light rail from a social equity perspective.

**Transportation Problems**

Transportation, outside of walking, started to be intertwined with people’s lives
when wheels were first fixed on carts around 3500 BC (Bellis, The History of
Transportation, website source.). Karen Lucas pointed out that the history of
transportation has always been closely tied with that of urban development (Lucas, 2004).
She further explains that transportation infrastructure is often responsible for shaping the
layout of towns and cities, and thus determining where people live, work, shop, go to
school, and carry out their leisure activities (Lucas, 2004). Some seminal theories in
economic geography have tried to examine the interactive relationship between
transportation and urban development and urbanization. For example, by influencing total
costs, transportation brought the emergence of geographical production specialization and
further enabled trade to appear on the stage of history. Another example is the theory of
“network development” which explains how social activities accumulate along with
transportation development. In this theory, the creation of a transportation network has
six steps: scattered points; penetration lines and port concentration; development of
feeders; beginning of interconnections; complete interconnection; and emergence of high
priority links. The “core-periphery” model explains the spatial development wherein
transportation development serves as the trigger. Theories come from practice. In the history of the United States, the Erie Canal and the Pennsylvania Main Line, an old railroad line, all exemplifies these theories and the early urbanization period of many U.S. cities. In recent times, the completion of the U.S. national highway system increased the motorized urban mobility for people to achieve destinations that were not reachable within walking distances. As a result, enhanced mobility combined with economic and demographic changes increased suburban housing, and the moving of industrial and commercial activities from urban centers to the periphery areas.

In economics, transportation is referred to as the "merit good", which means that the transportation system is subject to the ‘natural’ distributional function of the free market which may disproportionately distribute transportation services, resulting in a disadvantage to certain groups or communities. This is true in the real world. In 1950s, automobile became popular and the highway system began to connect American cities, which largely stimulated American people’s mobility. However, when white people moved to suburban areas for clean air, water, and a serene countryside lifestyle, the Blacks were trapped in the old city cores. Suburbanization has brought large amounts of jobs that fit minority and low-income people to the periphery, which has caused what is called a spatial mismatch which is when there is an imbalance of jobs and housing in an area. This affects low-income and minority people the most because these groups often have limited access to automobiles or disposable income for travel. Because of these persistent inequities, policy intervention in transportation can attempt to balance the power of the “natural” distribution to improve the quality of life of every individual and community.
A number of scholars have shown that transportation policy can play a key role in controlling negative impacts arising from the transportation system such as accidents, noise, air pollution (Gorz, 1989; Whitelegg, 1993). Professor Michael Hill, in his book *Social policy: A comprehensive analysis* believed social policy should be "concerned with the role of the state in relation to the welfare of its citizens" (Hill, 1996, P. 4). He found that transportation policy had been omitted from this comprehensive analysis (Hill, 1996). Such failure to apply social science perspectives to transportation policy may have serious consequences. For example, it shows the failure of transportation studies to address public concerns about mobility. It also shows the failure to "make the links between progressive democratic aspirations, such as reducing unemployment or addressing health inequalities, and the system of transport delivery in advanced industrial societies" (Root, 2003). Banister and Hall (1981) also raised criticism of transportation policy. They asserted that the absence of adequate transportation provisions has important consequences for employment, education, housing and land-use policy and thus the distribution of these social aspects.

Policy intervention also appears in the transportation planning tradition, especially in terms of the distribution of state funds. For instance, funds or subsidies usually support specialized transportation such as paratransit services for people who are unable to access the public system because of a disability. Other specialized transit uses can be for destinations, such as school trips for young children or hospital outpatient visits. In this form, transportation is an expensive item of government expenditure. Decisions about how the state spends money on transportation projects have traditionally stimulated wide and long-lasting debates. Normally, transportation planners use cost-benefit analysis
(CBA) to evaluate alternative projects. However, this method does not include external costs as a component of the costs of transportation, which have led to transportation spending decisions that favor increased road capacity over public transportation services, cycling, and walking amenities. The overall effect of these methods has resulted in the greatest benefits from state transportation budget benefiting those who are already well-off in terms of transportation provision (mainly motorists), and the least benefits to those who are lack adequate transportation provisions (mainly people who do not or cannot drive) (Lucas, 2004). This consequence has deviated from the purpose of making social and public policy which aims to serve the welfare of the population as a whole. Social inequality occurs because of the commencement of incomprehensive social policies, which is not ideal.

**Spatial mismatch**

The spatial mismatch hypothesis was firstly discussed by Kain in his 1968 paper *Housing segregation, negro employment, and metropolitan decentralization*. Since then, the discussion around this issue has continued with earnest. Literally speaking, spatial mismatch talks about the existence of distance between the places of living and working. This phenomenon can be observed among minority ethnics and low-income groups who tend to reside in central city locations while working in suburban areas. This situation has resulted from the movement of people and firms from central city areas to the suburbs during the past several decades, resulting in growing employment problems for those who continue to live in the inner cities. Researchers have always been trying to better understand the mechanisms which create the mismatch problem, i.e. what has caused this phenomenon. Seemingly, this idea is widely accepted by social scientists in popular
discussions of employment problems. However, the empirical support for the hypothesis has always been quite controversial as it was over 40 years ago when it was first proposed. Kain’s original paper which was the first to demonstrate this concept was immediately disputed (Offner and Saks, 1971). Grengs (2000) also bravely contended that modal mismatch (first proposed by Blumenburg and Manville, 2004), instead of spatial mismatch, should be the reason that caused the lower job accessibility of black people. Thus, improving access to automobiles, while also improving public transportation, can more effectively address the black unemployment issue.

The debate between spatial mismatch and modal mismatch can also be referred to as the competition between public transit and private transport via the automobile. This debate has been rooted in the question of how to wisely distribute governmental transportation spending to make more efficient financial policy intervention.

**Background of spatial mismatch.** The spatial mismatch hypothesis presents a viable way to explain the employment problems faced by African Americans and low-income individuals who reside in the central city. This hypothesis claims that the geographical distance that results from the dispersing land-use pattern and automobile oriented urban spatial structure is the main cause for low employment rate of these people.

However, since Kain proposed the spatial mismatch hypothesis, the discussion of its validity has continued. At first, people wanted to verify whether the movement of people and firms from central city areas to the suburbs over the past several decades caused growing employment problems for those who continue to live in the inner cities. Evidences from ‘Urban Residential Choice’ (Mill, 1972) start from an assumption that
employment is fixed in the central city and people are free to make their residential choice from the entire metropolitan area. Hence, people usually face a trade-off situation where they could choose either higher housing prices in the central city or longer commute times from the suburban areas. Research shows that arguably the majority of rich people in the United States tend to live far away from the urban core to enjoy clean air and peaceful country life. However, as spatial mismatch continues to allow for employment to be decentralized, housing choices become much more complicated. Experiences suggest that manufacturers are likely to choose suburban locations where they reap benefits such as lower tax rates and expansive greenfields to develop a large manufacturing plant. Eventually suburban ‘subcenters’, such as shopping malls will develop to provide retail and consumer services for the local people. Therefore, many entry-level and less technical jobs will relocate in the suburban areas, making it challenging for inner city residences to obtain an affordable home near their place of employment. Some people are not free to choose their most preferred residential locations because euclidean zoning practices can be restrictive with restrictions such as minimum size lots that are unaffordable to low-income families, many of which are minorities. These disadvantages make it more costly and difficult for these groups to obtain employment in suburban locations. For those who do obtain such employment, the higher cost of travel (in time or money) will mean lower net wages for the time actually spent working. This is especially true for low-income people in inner-city areas who do not own cars and who find public transportation not widely available to various parts of their metropolitan areas (Holzer, 1986).
Furthermore, blacks and other low-income groups already face other disadvantages in the labor market, such as lower skills, fewer social connection and employment discrimination to name a few. Together with the aforementioned barriers, inner-city blacks and low-income people may face lower net wages. The costs of extended commutes for those obtaining employment farther from their homes will reduce their net wages earned at suburban jobs. If net wages are reduced below the minimum acceptable wages of these workers, they will not accept employment at all, preferring to continue searching or to drop out of the labor force together (Holzer, 1986).

In summary the literature finds the dispersal of jobs that place a growing share of metropolitan jobs in distant suburbs, racial discrimination in housing that confines racial minorities to the urban core, inadequate transportations that offers a poor linkage between the central city and suburbs, and special characteristics of many employment related trips that are complex and involve multiple destinations such as reaching childcare facilities or other services, have resulted in concentrated poverty among African Americans and lower-income individuals in central cities. Spatial mismatch tries to explain this phenomenon.
The debate. The traditional formulation of spatial mismatch hypothesis is challenged by many transportation scholars in recent years (Grengs, 2010; Bander, 2000; Blumenberg and Ong, 2001; Ong and Miller, 2005; Preston and McLafferty, 1999; Shen, 1998). They contend that it places too much emphasis on the physical distance to employment without proper regard to travel mode. The barriers that prevent workers from reaching distant suburban jobs is not so much geographical distance as a lack of reliable personal transportation that owning a car brings—the modal mismatch thesis (Blumenberg and Manville, 2004).

From the transportation policy perspective, the conventional understanding of spatial mismatch has largely produced public policy aimed at linking workers to jobs with ‘reverse commute’ using public transit (Transit Cooperative Research Program, 1999). Policy examples include some of the unsuccessful ones, such as the Urban Mass Transportation Administration (UMTA) demonstration projects in the 1960s which tried to bring public transportation to the urban poor, and some federal government projects, such as Jobs Access and Reverse Commute (JARC) program started in 1998 which included both urban and rural welfare recipients, and the Transportation Equity Act for the 21st Century (TEA-21). However, if travel modes are more central to job accessibility than location, then our public policy responses to spatial barriers to employment may be misguided if the focus is exclusively on geographic distance. The new conception of spatial mismatch raises a question of whether policy makers are relying too heavily on transit as a solution for overcoming the spatial barriers that harm the job prospects of inner-city African Americans and low-income group, and places more emphasis on identifying the appropriate role for public transit among a diverse set of policy responses
(Blumenberg and Hess, 2003). Some researchers argue that the policies that aim to help those without cars gain access to automobiles may be one of the more effective means of improving the employment outcomes of inner-city residents (Grengs, 2010; Blumenberg and Ong, 2001; Cervero et al., 2002; Lucas and Nicholson, 2003; Raphael and Stoll, 2001; Shen, 1998; Taylor and Ong, 1995; Wachs and Taylor, 1998).

**Civil Rights and Transportation Policies**

Historically, the fighting for civil rights can be traced back to the early to middle 20th century when large numbers of African Americans migrated to the north states and west coast cities, making the once centrally located black community visible to the rest of the country. Ongoing and pervasive discrimination led to continued fights for opportunities for jobs, education, health, and other types of social services and have led to a series of codified standards aiming to measure, mitigate, and prevent social inequality. However, many researchers find that inequities in transportation and spatial mismatch continue. Now, a brief discussion of the transportation-related civil rights demonstrations and public policies will take place.

The anti-segregation bus boycotts in Montgomery, Alabama in August, 1955 is a well-known transportation struggle. Lead by reverend Martin Luther King, Jr., this movement lasted for more than a year and finally resulted in the desegregation of the bus system in late 1956, sparking the modern civil rights movement in the United States. This resulted in public concerns for both the distribution of the benefits and burdens of transportation systems, as well as for inclusiveness of the transportation planning process. Several years later, the Watts Riots in 1965 represented the Los Angeles civil rights protests and helped the government realize that inadequate transportation might
contribute to high rates of unemployment among the black urban population (Kain and Meyer, 1970).

During the Civil Rights movement, the treatment and rights of African Americans received a great deal of attention. As a result, many federal laws were passed and enforced to ensure fair treatment of this historically suppressed people. Motivated to address the crucial issues black people and low-income populations suffer from, policies pertaining to the civil rights and inequitable transportation problems have emerged. These obligations arise under Title VI of the Civil Rights Act of 1964, the 1994 “Environmental Justice” Executive Order 12898 entitled “Federal Actions to Address Environmental Justice in Minority Populations and Low-Income Populations”, and in various federal surface transportation statutes. For example, federal government policies have attempted to promote a wide range of public transportation service types, such as jitneys, shuttles, demand responsive services, and taxis, along with the primary mode of fixed route service (bus), in order to improve mobility of African Americans. In regards to transportation mobility policy, the two most notable periods occurred during the 1960s and 1990s when there were highly publicized and severe civil rights or race relation disturbances. The efforts of the 1960s were more concerned with quelling social unrest, such as the UMTA demonstration projects. Similarly, the efforts of the 1990s focused more on reforming the federal welfare system than genuine efforts to combat poverty.

Title VI of the Civil Rights Act of 1964 provides that there should not be any discrimination when people participate in and receive the benefit of any program or activity receiving Federal financial assistance (Overview of Title VI of the Civil Rights Act of 1964). The law allows many people to benefit from transportation investments,
such as the quantity of transit service. In addition, Title VI provides “meaningful opportunities for public involvement by members of minority populations and low-income populations during the planning and development of programs, policies, and activities”. (DOT Order, 62 Fed. Reg. at 18380; see FHWA Order ¶5 (c)(1)-(4).) Following the instruction of the Title VI, the 1960s transportation policy studies attempted to tackle issues for the social poor by providing public transportation projects. One of the earliest examples of research focusing on the travel needs of low-income persons is Oscar Ornati’s *Transportation Needs of the Poor* (1968) whose publishing coincided with the UMTA demonstration projects of the late 1960s (Sanchez, 2008).

Other discussion about transportation issues for low-income people has been associated with land-use patterns, social, and economic conditions of urban areas. In 1968, the National Advisory Commission on Civil Disorders (NACCD) released its report on the causes and effects of riots in US cities. Among their recommendations for enhanced employment opportunities for central city residents was the creation of improved transportation links between old central city neighborhoods and new job locations in the suburbs (NACCD, 1968).

Many years later, the Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991 promised to improve the mobility of the economically disadvantaged groups through “intermodal connections between people and jobs, goods and markets, and neighborhoods” (Bullard, 1996). Subsequently, the Personal Responsibility and Work Opportunity Act of 1996 (PROWA), “welfare-to-work”, and job access programs again brought attention to low-income mobility problems (Willis, 1997; US DOT, 1998). From the perspective of civil rights regulations, U.S. DOT’s Order 5610 which implemented
the Environmental Justice Order prevented activities that can cause any adverse effect on minority and low-income populations while receiving benefits from DOT programs. (DOT Order 5610.2, 62 Fed. Reg. 18,377, 18,381 [1997].) This Order also required an “equity analysis” to be conducted by regional and local agencies to enable early identification of any risk of discrimination and ensured the program, policy or activity to be developed positively and correctively (Golub et al., 2013). Moreover, the Transportation Equity Act for the 21st Century (TEA-21) established the Job Access and Reverse Commute (JARC) program in 1998 which authorized an annual amount of $150 million for JARC grants for the fiscal years 1999 to 2005 (Sanchez & Schweitzer, 2008). In 2005, the Safe, Affordable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU) authorized a total of $727 million for JARC grants for fiscal years 2005 through 2009 (Sanchez and Schweitzer 2008).

**Plan for thesis**

Section 1 introduces the motivation to conduct this study and the backgrounds of current transportation problems and relevant policy supports. Section 2 provides a more academic background of the transportation literature. The next Section talks about the facts that relate to the case study for this research: general information about Phoenix Metropolitan area and the Phoenix Light Rail system which opened for operation in 2008. Methodologies are introduced in Section 4 with a brief review of accessibility methods in the literature. In the following Sections, the results and discussion are presented. The paper ends with a conclusion and policy suggestions for the improvement of transportation planning systems.
Literature Review

Previous work on disparities in job accessibility

Definitions of accessibility. Many researchers have defined accessibility in a variety of ways. As early as 1959, Hansen provided the well-known definition as “the potential of opportunities for interaction” (Hansen, 1959). During the 1970s, accessibility was defined as “the ease with which any land-use activity can be reached from a location using a particular transport system” (Dalvi and Martin, 1976), “the freedom of individuals to decide whether or not to participate in different activities” (Burns, 1979), and “the benefits provided by a transportation / land-use system” (Ben-Akiva and Lerman, 1979). Around two decades later, Cervero, Rood & Appleyard (1995) defined accessibility as “an indicator of opportunity to efficiently reach places”, which offered a very important concept that accessibility can serve as a performance indicator to reflect the degree to which transportation decisions are helping to economize on commuting and promote social equality objectives. Similarly, Kawabata has pointed out that “Accessibility can be seen as the bridge connecting transportation system performance and the land-use pattern, which provides important information regarding urban spatial structure” (2008). Most sources use accessibility or job accessibility as an indicator to assess the effectiveness of transportation policies, land-use policies, or to provide evidence for decision makers. The evaluation research of Geurs and Wee (2004), focused on passenger transport and defined accessibility as “the extent to which land-use and transport systems enable individuals to reach activities or destinations by means of a (combination of) transport modes”.

16
**Accessibility as a performance indicator.** As stated above, accessibility can serve as a performance indicator to aid research from various perspectives. Based on the value of accessibility measurement, it is possible to compare different transportation modes to find out which mode should be promoted. Also, people can evaluate the impact from transportation improvements and from land-use developments by calculating accessibility metrics, in order to investigate different policies’ effects in changing the employment rate. As an example, Wachs had stated that “physical accessibility can be used as a social indicator” (Wachs, 1972). Such examples are not difficult to find among the accessibility literature. Cervero et al. (1998) and Gutierrez (1998) measured accessibility with different research goals. Cervero et al. were aiming to use job accessibility to guide long-term transportation planning in the San Francisco Bay Area from 1980-1990. The results showed that employment centers where highly skilled people reside have the best job accessibility. Low-income and inner-city residents have the worst occupational mismatch. On the other hand, Gutierrez’s study focused on network system in the Spanish Infrastructure Master Plan. His results showed that the chief nodes of the network and the surrounding territory have imbalances in accessibility. The accessibility indicator used in Gutierrez’s study was specially created for measuring network efficiency, which differed from the accessibility of one place. The measure can indicate that a place that has high accessibility because of a road connecting it in the area cannot represent that the whole area also has high accessibility since the road network may be inefficient. Another European study aiming to evaluate the United Kingdom government policy of accessibility planning incorporated accessibility measurement. Here, the merit of accessibility is not only in indicating the effect of policy, but also in
that it is adopted by the national government of the UK to create a new type of urban planning – Accessibility Planning – to tackle the social exclusion issue (Lucas, 2006).

Other studies also have their focus on the social equity problem. Social exclusion can be understood as a layer of social inequality. For instance, Fan et al. (2012) studied the light rail impacts on the employment issue, from an equity perspective. To exemplify the consideration of equity, Fan used accessibility indicators to compare the accessibility value among different income groups. Results showed that the LRT produces job accessibility benefits for all workers. Another example of equitable perspective is conducted by Grengs (2013), whose study had a different focus. Instead of doing research in the realm of home to work commuting, Grengs emphasized non-work trips and applied non-work accessibility to indicate social equity conditions in Detroit. The results found that the vulnerable groups (African Americans, Hispanics, low-incomes, and those in poverty) have a disadvantage for shopping and supermarkets. Non-work accessibility varies substantially by the purpose of the trip. In a newly published study, Golub, et al. (2013) also draw on the social justice principles and conducts a proactive study to evaluate the proposed transportation projects. They come up with the conclusion that virtually all neighborhoods of the San Francisco Bay area suffer from substantial gaps in accessibility between car and transit modes.

In addition, accessibility can be calculated based on different spatial scales and thus serve a wider range of studies. One example is from Grengs et al., 2010 which estimated regional accessibility values for both San Francisco and Washington D.C. With the help of regional accessibility metrics, the two metropolitan areas can be compared to find out which urban form is better to provide greater accessibility. “The advantage of
regional accessibility over individual level accessibility is that it provides an assumption that the regional accessibility is equally applicable to each person in the region, which serves as a potential for people to access destinations.”(Grengs., et al., 2010) This research has another unique conclusion compared to the previous studies that “Besides mobility, proximity and connectivity (like internet) there are other ways to achieve accessibility”. Additionally, the authors pointed out that “mobility and proximity have a contradictory relationship in that higher mobility may lead to sprawl development, ruining the proximity and reducing accessibility. High proximity may have low speed (less mobility) but may help accessibility”.

**Job accessibility and spatial mismatch**

In the United States, minorities and lower-income populations have relatively lower rates of automobile ownership when compared to non-minority populations (Hansen. J. 1996; Guiliano, 2005; Hess. D. 2005; Faiz. A., 2011; Wells. K., et al. 2011; Fan et al. 2012; Foth. N., et al. 2013). Moreover, low-income people in the United States are generally found living in the inner-city while working in the suburbs where many job opportunities for low-skill workers are found. To complicate matters, affordable housing opportunities in the suburbs are traditionally few. (Glaeser, Kahn, & Rappaport., 2008; Kain, 1968; Kain, 1992). However, in a country where the dominant form of transportation is the automobile and highways have received funding priority for nearly a century, public transportation has lost its market share. Public transportation is the major transportation mode for low-income and minority populations. Since most of them are unable to own a private vehicle and public transit routes are generally sparse, these
populations have fewer job options due to the limited area around public transportation nodes.

This situation of “uneven access to job opportunities” (Fan et al., 2012) is partially caused by the imbalanced job-housing distribution which is also called “spatial mismatch” (Kain, 1968). During the 1980s, many areas of the country experienced considerable employment decentralization (Cervero, 1989; Wu, 1994; Cervero and Wu, 1997), which may have started the spatial mismatch phenomenon. The spatial mismatch hypothesis holds that the physical isolation or inaccessibility of the inner-city is an important cause of unemployment and poverty of inner-city residents. Raphael has studied the spatial mismatch hypothesis and black youth joblessness in the San Francisco Bay area and found that accessibility explains 30-50 percent of the black youth unemployment rate (1998).

On the other side of the coin, a concept of modal mismatch has been introduced (Grengs, 2010) to provide a different theory about the issue of “uneven access to job opportunities”. The modal mismatch perception contends that spatial imbalance cannot fully explain the lower accessibility suffered by minorities and lower-income populations. Therefore, the solutions based on the spatial mismatch hypothesis cannot solve the access problem effectively by themselves. By assessing the gap between car-based accessibility and transit-based accessibility, researchers tend to come up with the same conclusion that cars can provide higher accessibility than transit. Given this finding, the modal mismatch theory promoters recommend that subsidies be spent to purchase low income people cars and not on transit (Cevero, 2002). More directly, Blumenberg and Manvill believed “no policy should deny a single car to a poor family” (Blumeberg and Manvill, 2004). Grengs
stated that the spatial mismatch theory has shortcomings that can mislead policy makers to merely focus on public transit and land-use policies to solve the mismatch problem. In another study, Grengs compared auto and transit-based accessibility and found that most racial minorities and low-income persons are advantaged in the ability to reach jobs, while a number of them are disadvantaged by virtue of lacking an automobile in spite of residing in advantaged locations (Grengs, 2012).

However, in two studies of San Francisco Bay area, Kawabata (2006, 2008) confirmed that greater job accessibility relates more to shorter commuting times for driving alone as well as for public transit. Kawabata et al. also found that the degree of this relationship is considerably higher for transit than for driving alone. As a result, they recommended that urban and transportation development should enhance public transit.

**Measures of Accessibility**

Accessibility is widely used in a number of scientific fields such as transport planning, urban planning, and geography. It also serves as a social or economic indicator for policy making. Several scholars have written literature reviews on accessibility measures. The majority focuses on different research perspectives of accessibility, such as location accessibility (Song, 1996; Handy and Niemeier, 1997), individual accessibility (Pirie, 1979; Kwan, 1998) or economic accessibility (Koenig, 1980; Niemeier, 1997). However, Geurs and Wee (2004) attempted to look at accessibility measures holistically and assessed the usability of these measures in different fields of study, such as land-use change, transportation policy evaluation, and related social and economic analysis.
As previously mentioned, accessibility has been defined in a number of different ways. People may define accessibility from different perspectives or by emphasizing different components of accessibility. Geurs et al. identified four types of components of accessibility measures. They are the land-use component, the transportation component, the temporal component, and the individual component where each type of component sometimes contains more than one factor that influences the accessibility measure. The land-use component refers to the spatial distribution of destinations, such as jobs, schools, and shops, and also refers to the distribution of demand, such as residential locations. The larger the spatial distance between the origin and destination, the less accessibility is assumed, all other factors being equal. Vehicle speed, road condition, and network efficiency are all possible reasons for a different accessibility measure. The temporal component reflects constraints such as a shop's hours of operation. The individual component is very important in accessibility calculations in that it considers individuals’ ability and needs, such as income, social class, and availability to buy or borrow a car. Several studies have shown that incorporating individual components greatly affects the results, by incorporating occupational matching into the calculation formula (Cervero et al., 1997; Geurs and Ritsema, 2003).

Ideally, accessibility measures should embrace all the components explained above and be sensitive to changes relating to all aspects of the component. However, it is not realistic to incorporate every factor into one accessibility measure. Researchers tend to conduct their studies from different perspectives and have special focuses on certain types of components. As a result, accessibility measures can be categorized by perspectives into four groups (Geurs and Wee, 2004).
**Infrastructure-based accessibility measures.** In transportation policies, infrastructure-based accessibility measures play an important role (Ypma, 2000; Ewing, 1993) in evaluating the efficiency of transportation systems. Certain measures include travel times, congestion, and speed on the road network. For example, traveling speed is used in the Dutch National Transport Policy Plan to assess accessibility (AVV, 2000). The UK Transport 2010 Policy Plan also utilized congestion as an accessibility measure (DETR, 2000). However, although being easy to interpret and communicate with stakeholders and decision makers, this type of measurement has serious shortcomings because it does not reflect the location, land-use or individual component and may lead to inaccurate results. For example, a transportation system that has high accessibility when using travel time as the measure may end up causing more urban sprawl. Another example provided by Linneker (1992) shows that inner London has the highest transportation costs but has the highest job accessibility in UK.
**Location-based accessibility measures.** Several location-based accessibility measures are used in the literature. They can be further grouped into three sub-categories—distance measures, contour measures, and potential accessibility measures.

**Distance measures.** Distance measures normally use the distance between origin and destination locations to represent the accessibility. They are the simplest class of location-based accessibility measures because they simply assume that a longer distance means weaker accessibility. In land-use planning, distance measures are often used to represent the maximum distance or travel time to a place or transportation stations, such as bus stops, train stations. One example of distance measures is called 'relative accessibility which was developed by Ingram (Ingram, 1971).

**Contour measures.** When referring to the accessibility between one origin and more than one destination, contour measures are often used. A contour measure is also referred to as integral accessibility (Ingram), an isochronic measure, cumulative opportunities, proximity count, or daily accessibility. The main idea of contour measures is to count the total number of opportunities that can be reached within a certain travel time, distance limit, or cost limit (Geurs and Wee, 2004). It is the favored accessibility measure used in urban planning studies (Gutierrez and Urbano, 1996; Bruinsma and Rietveld, 1998; Fan, 2012; Golub, 2013). This measure has its advantages in that it is easy to operationalize, interpret, and communicate (Geurs and Wee, 2004). However, it does not take individual components into account, i.e. the measure assumes each person at the location has the same level of ability to achieve the reachable destinations.
**Gravity-based measures (also called potential accessibility measures).** Another popular accessibility measure in urban planning studies is what is called a Gravity-based measure or a potential accessibility measure. Gravity-based measures take the theory of distance decay into consideration and use impedance functions as the most important part of the accessibility formula. The measure assumes that people’s traveling activities are partially the result of a destination’s attractiveness. Also considered is the proximity of the destination. The closer the destination, the more likely people are to go there. The measure has a typical form as follows:

\[
A_i = \sum_{j=1}^{n} D_j e^{-\beta c_{ij}}
\]  

Where \(A_i\) is a measure of accessibility in zone \(i\), \(D\) represents all opportunities in zone \(j\). \(c_{ij}\) is the cost of travel between \(i\) and \(j\). \(\beta\) is the cost sensitivity parameter.

Several different types of impedance functions appear in the literature, such as power, Gaussian, and logistic functions. Among them, the negative exponential function is most frequently used and the most closely tied to travel behavior theory (Handy and Niemeier, 1997). The gravity-based measure has the potential to evaluate the combined effect of land-use and transportation components, and can also be developed to incorporate a competition effect. For example, Williams and Senior have interpreted a concept of a double constrained spatial interaction model (Wilson, 1970, 1971) into a gravity accessibility measure (Williams and Senior, 1978) to account for competition effects. Functions are as follows:

\[
a_i = \sum_{j=1}^{n} \frac{1}{b_j} D_j e^{-\beta c_{ij}}
\]  

25
In this modified version, the balancing factor $a_i$ and $b_j$ represent the volumes of flow originating from zone i and destined at zone j. The equations are trying to balance these two flows with the number of activities in zone i (e.g. workers) and j (e.g. jobs). The balancing function is useful in assessing accessibility where competition occurs in both the origin and destination locations (Geurs and Wee, 2004).

**Person-based accessibility measures.** Space-time prisms are used in person-based accessibility measures to describe the travelling patterns of an individual or household. It is founded in the space-time geography research of Hagerstrand (1970). Application of the space-time approach in travel behavior research is getting more and more popular (Ettama and Timmermans, 1997) but its overall usage is still relatively rare.

**Utility-based accessibility measures.** Utility-based measures translate accessibility as the utility outcome of a set of transportation choices. The results from utility-based measures can address the decision to choose one transportation mode from a group of transportation options. Two types of utility-based accessibility measures can be identified in the literature. First one is based on random utility theory and uses the logsum as an accessibility measure (Ben-Akiva and Lerman, 1985): 

$$ A_i = \ln(\sum_{k=1}^{m} e^{V_k}) $$

$A_i$ represents the maximum expected utility. $V_k$ stands for the utility of one specific type of transportation. Due to its limited comparability with other transportation modes, this equation is often modified by being divided by a travel-cost coefficient:
$$A_i = -\frac{1}{\lambda} \ln(\sum_{k=1}^{m} e^{\nu_k})$$  \hspace{1cm} (5)

However, the logsum measure is not often used in practices. The second approach to measure utility-based accessibility is based on the doubly constrained entropy model (Martinez, 1995; Martinez and Araya, 2000):

$$A_i = -\frac{1}{\beta} \ln(a_i)$$ \hspace{1cm} (6)

$$A_j = -\frac{1}{\beta} \ln(b_j)$$ \hspace{1cm} (7)

$$A_{ij} = -\frac{1}{\beta} \ln(a_i b_j)$$ \hspace{1cm} (8)

Here $A_i$ represents the expected benefits per trip generated; $A_j$ represents the benefits per trip attracted; $A_{ij}$ represents the benefits per trip between zone $i$ and zone $j$.

The utility-based accessibility measures take into account most of the influential components and especially they can reflect transportation users’ benefits from both land use and transportation projects. Therefore, it is widely used in economic studies.
Case Study

Background of Study Area

*Figure 1. Map of Phoenix Metropolitan Area*
Phoenix Metropolitan Area. The Phoenix Metropolitan Area—the 14th largest metro area in the United States—centered on the city of Phoenix, includes much of the central part of the U.S. State of Arizona (United States Census Bureau, 2010). It is also referred to as the Valley of the Sun and the Salt River Valley or Metro Phoenix. The Office of Management and Budget defines a metropolitan area as the core city plus its county and any nearby counties that are economically dependent on the core. However, since Arizona has relatively large counties and a harsh desert landscape, much of the Metropolitan Area is rural or completely uninhabited landscape. The core part of the Phoenix Metropolitan Area is the urbanized area, which is far smaller than the entire land area of the Metropolitan Area (U.S. Census Bureau, 2000). Containing major cities of Phoenix, Mesa, and Glendale, the United States Census Bureau designates the area as the Phoenix-Mesa-Glendale Metropolitan Statistical Area (MSA).

During the decade from 1990 to 2000, the population of the Phoenix Metropolitan Area increased by 45.3 percent. At the same time, the average population growth of United States was 13.2 percent. Comparing these two rates, Phoenix Metropolitan Area is much faster and makes Arizona the second fastest growing state in the nation during the 1990s. (United States Census Bureau, 2001) As of April 1, 2010 the Census Bureau reported that the two-county metropolitan area is home to more than two-thirds of Arizona's population.

The 2010 census showed that there were 4,192,887 people, 1,537,137 households, and 1,024,971 families residing within the MSA. The racial makeup of the MSA’s population was 73.0 percent White (58.7 percent White Non-Hispanic), 5.0 percent Black, 3.3 percent Asian, 2.4 percent American Indian and 16.2 percent other or mixed race. 29.5
percent were Hispanic of any race (2010 – 2010 Demographic Profile Data, U.S. Census Bureau).

In terms of income level, the 2010 census data showed that the median income for a household in the MSA was $50,385 and the median income for a family was $58,497. The per capita income was $24,809 (2010 American Community Survey 1-Year Estimates, U.S. Census Bureau).

The Phoenix Metropolitan Area is served by several controlled-access freeways, including Interstate 10, Interstate 17, US 60, SR 51, Loop 101, SR 143, and Loop 202, Loop 303.

The Phoenix Sky Harbor International Airport is the major airport of the Metropolitan Area. In 2010, Phoenix Sky Harbor International Airport was the 24th busiest passenger facility in the world and the 10th busiest in the United States where three terminals serve more than 38 million passengers (Phoenix Sky Harbor Official Site).
**City of Phoenix and Metro Light Rail.** As the state capital and the largest city in the state of Arizona, the City of Phoenix is located in the northeastern reaches of the Sonoran Desert, is characterized by a subtropical desert climate, and is home to 1,445,632 people (2010 U.S. Census Bureau). According to the United States Census Bureau, the city has a total area of 517.9 square miles (1,341 km²), which makes it one of the largest cities in the United States. Among the total area, 516.7 square miles (1,338 km²) of it is land and 1.2 square miles (0.6 km², or 0.2%) of it is water. In addition, Phoenix is the county seat of Maricopa County which is the 12th largest metro area by population in the United States with about 4.2 million people in 2010 (2010 U.S. Census Bureau data).

The Phoenix light rail system, officially named the Metro Light Rail, is a 20 mile (32 kilometers) light rail line serving the cities of Phoenix, Tempe, and Mesa. Valley Metro, the agency who oversees Metro Light Rail, started construction in March 2005 and began operation on December 27, 2008. Since it opened, it has proven to be a big success with an average daily ridership that is 33,000 is higher than the forecast of 26,000 (New York Times 2009) Since it first opened in 2008, Metro Light Rail's annual ridership has been continuously growing up from 5,580,860 (6 months after operation in 2009) to 14,286,093 (Valley Metro, 2012), making it the 12th busiest light rail system in the country.
Figure 2. Phoenix Metro Light Rail System Map

As a part of the Valley Metro public transit system which includes buses, the Phoenix Metro Light Rail (METRO) serves the cities of Phoenix, Tempe, and Mesa. It travels through downtown Phoenix and, offers access to Phoenix Sky Harbor International Airport via the Sky Train. It also links two of the four campuses of...
Arizona State University. Phoenix Light Rail’s vehicles were designed for a maximum speed of 55 mph, and have to complete the 20 mile route in 65 minutes, including station stops (Valley Metro Official Site). The line was projected to initially accommodate 26,000 passengers per day, or more than eight million boardings in its first year. Results from Valley Metro (see figures below) show that the light rail has experienced constant growth since the beginning. In 2012, its estimated daily ridership has increased to 43,310 and the number of passengers was just over 14 million, making it the 12th busiest light rail system in the country (Valley Metro Official Site).

![Average Daily Ridership](http://www.valleymetro.org/images/uploads/daily_ridership_012413.gif)

*Figure 3. Average Daily Ridership of Phoenix Light Rail, 2010—2012*

Source: Valley Metro

Methods

Accessibility Calculation Structure

At its core, the cumulative opportunity method of accessibility calculation uses transportation and demographic data to generate accessibility measures for each neighborhood of the region (Golub & Robinson, 2013). The accessibility measures are comparable within the region among different time periods. The basic concept of the accessibility calculation can be described as follows:

Figure 4. Total Monthly Ridership of Phoenix Light Rail, 2010—2012
Source: Valley Metro
Sum up the total number of travel destinations (jobs, schools, hospitals, or other types of social services) that are reachable within certain time periods (15, 30, 45 minutes) by transportation modes such as automobiles, public transportation and, bicycles.

As previously discussed, this study focuses on three components: job accessibility, public transit, and social equity, which makes employment the major travel destination. Therefore, job accessibility measures are the numbers of jobs and employment opportunities reachable within a certain time period. The study area is the Phoenix Metropolitan Area, especially the urbanized portion. Demographic data was collected and aggregated to the geographic level of traffic analysis zones (TAZ) and they are the basic spatial unit of this study. Normally, traffic analysis zone is the geographical unit that is used in the conventional transportation planning models and transportation-related studies. This was followed by the calculation of job accessibility measures for each TAZ. Time limits adopted in this study are 30 minutes and 45 minutes. Because we are interested in whether the light rail changes job accessibility measures were calculated prior to the light rail was built and after the light rail was built. Below outlines the steps that were taken to conduct the calculations:

1. Calculate both 30 minute and 45 minute job accessibility measures for each TAZ at two time periods—before the light rail and after the light rail. Take 30 minute as an example, at first we find out the 30-minute “neighborhood” for each TAZ. In the end, the number of TAZ “neighborhoods” is same as as the number of TAZs. Using the travel time data set (introduced in Data Requirement section), all TAZs which have a travel time less or equal to 30 minutes are recognized as members of the “neighborhood”.
Secondly, we add up the total number of employment opportunities of each “neighboring” TAZ which results in the job accessibility measure.

2. Compare job accessibility measures before and after the light rail and both time periods of 30 minutes and 45 minutes. Comparison methods include differences (after-accessibility minus before-accessibility) and percent change (difference data divided by before-accessibility).

3. Compare the results from the “before-after” comparison among different income groups and race groups, aiming to find out which population group has a higher impact from the creation of the light rail.

See the figure below for a graphic representation of the methodology of accessibility calculation.
The output of the basic job accessibility calculation is a dataset containing the total number of jobs reachable within a specific time in a particular TAZ. Since we consider different travel modes for the home to transit station trips, the original travel time data is grouped into categories by travel modes—walking, park and ride, and kiss and ride. So the same TAZ pair may have different travel times depending on what mode people choose when accessing transit stations. Therefore, our results of job accessibility
have three categories divided by travel modes where each category has two time limits. Not all TAZs appear in the accessibility dataset and different categories may end up with different TAZs because of the different travel times. The absent TAZs are usually the ones that do not have enough available public transit services.

In equation form, the accessibility calculation is represented as follows:

\[ A_{nmT} = \sum_i J_{imT}, t_{nim} < T \]  \hspace{1cm} (9)

Where \( A \) is the accessibility measure of TAZ \( n \), with “home to station” mode \( m \), within time limit \( T \). \( J \) is the job opportunities within TAZ \( i \) in TAZ \( n \) neighborhood.

However, obtaining accessibility measurements of each TAZ is only the first step of this study. The next step is to find out which demographic groups’ job accessibility have changed more than other groups. Same accessibility calculation will be applied by demographic groups. Here five categories are incorporated: average of all, Hispanic, non-Hispanic, lower-income, and non-lower-income. By calculating and comparing job accessibilities of each group in each TAZ by job types, the demographic group that have their accessibility of a certain type of employment changing more than other groups of population is better benefitted from light rail. In the earlier discussion of spatial mismatch, it is known that minority people and lower-income people tend to work in entry-level jobs which mostly exist in retail and industrial employment types. This study is going to find out whether the Hispanic and lower-income people are able to access more job opportunities in retail and industry after light rail has been introduced.
Data Requirements

Maricopa Association of Governments (MAG) has provided and are responsible for providing socioeconomic data for TAZs (MAG Official Site.). Usually, MAG first allocates the population and employment data from the Regional Analysis Zones (RAZ) to one acre grids and then aggregates the data to TAZs. MAG also uses the TAZ forecasts of population, households, and employment as input to estimate auto and transit trips, VMT, and to prepare regional transportation, environmental and human services plans (Maricopa Association of Governments Official Site). In this study, 2008 TAZ data was obtained from MAG. The TAZ data falls into two types: the demographic and land-use data of each TAZ (which is called TAZ data here), and the TAZ to TAZ travel time data by public transportation (which is called “skims” here). The “skim” data is generated from the MAG 4-step transportation model which contains the whole public transit network of the Phoenix Metropolitan Area. Two sets of “skims” were obtained from MAG to represent before and after the light rail was built TAZ to TAZ travel times.

Moreover, considering the time spent on traveling from home to public transportation stations, the “skims” data falls into two parts: the “home to station” time and the “station to destination” time. As mentioned previously, “home to station” time includes three categories due to different travel modes. They are: Kiss and Ride (KNR), Park and Ride (PNR), and Walk or bike (WLK). Kiss and Ride represents a situation when the transit rider does not drive but gets dropped off at a transit station, like a bus stop or light rail station,. Park and Ride means the individual drives and parks his or her car near the transit stations and switched modes. This is more common to the light rail mode than the bus mode. Take the Phoenix Light Rail as an example. There are nine
“Park-and-Ride” parking locations along the 20 miles of light rail line, offering a total of 3,636 free parking spaces (Valley Metro Official Site.). The third mode includes both walking and bicycling. As the name suggests, people will just walk from home to the closest public transit stop or will ride bikes and park them at the bike racks on stations. They may also take their bicycle with them on the light rail or bus.

Spatial data for this study was obtained from the ASU GIS Data Repository to represent TAZ geography and transit networks. GIS is used for visualizing the case study background, demographic spatial distribution, and analysis results.

TAZ data obtained from MAG contained some categories of demographic data, such as population, households, and employment, but did not include ethnicity data for TAZs. The ethnicity data for this study comes from the American Fact Finder by census tract. Since census tracts and TAZs are not identical spatially, we use ArcGIS to convert census tract data and assign ethnicity and other data to TAZs.

Results

Mapping Demographics

Before delving into job accessibility calculations and the resulting comparisons, an examination of the demographic profile for all TAZs in the Phoenix Metropolitan Area is in order. All demographic data in this study comes from MAG TAZ dataset of 2008. First of all, the demographic distribution of TAZs is examined from three aspects: total population, total households (including both single family households and multifamily households separately), and total employment. Secondly, the spatial distribution of ethnicity data is visualized, including Hispanic, non-Hispanic (white
alone), one race alone, one race white, and one race black. The third aspect is economic data. Here both employment and income data are mapped. Four types of employment are mapped separately. They are public employment, retail employment, office employment, and industrial employment. These are the major categories of employment in the Phoenix Metropolitan Area. For income mapping, two quintiles of the MAG income classification were used including lowest income households and low income households since we intend to investigate light rail impact on lower income groups. All demographic data is mapped by the actual number without dividing by the area of each TAZ. The goal is to see where population and jobs locate over the study area without comparing demographics of TAZs.
Figure 6. All TAZs General Demographics, 2008. Total Population

Source: MAG 2008 Projections for Socioeconomic Input File
Figure 7. All TAZs General Demographics, 2008. Total Employment

Source: MAG 2008 Projections for Socioeconomic Input File
Figure 8. All TAZs General Demographics, 2008. Total Households

Source: MAG 2008 Projections for Socioeconomic Input File
Figure 9. All TAZs General Demographics, 2008. Single Family Households

Source: MAG 2008 Projections for Socioeconomic Input File
Figure 10. All TAZs General Demographics, 2008. Multi-family households

Source: MAG 2008 Projections for Socioeconomic Input File

The demographic data is colored from red to blue, with red representing the densest distribution and blue the least. The small map frame has a red rectangle which explains the positional relationship between what is showing in the major map frame and all TAZ area (Phoenix Metropolitan Area). We neglect the other parts of the region because they are similarly colored blue.

As we can see from figure 6 and figure 8 above, the total population and total households have similar concentration areas. Southwest and North Phoenix, Glendale, and North Chandler have the highest concentration of residents in the Phoenix
Metropolitan Area. On the other hand, employment tends to disperse more than residential distribution. Here employment data accounts for the total number of workers. We are able to recognize four employment hubs which are identified in red, representing the highest concentration of employment. There is the one farthest west —Luke Air Force Base, at the north end of the light rail line—downtown Phoenix, at the intersection of Interstate 17 and Arizona State Route 101, and Phoenix Sky Harbor International Airport. They are either urbanization centers or major transportation centers (airport and highway intersections). Even though the employment distribution is more dispersed than residential distribution, it is obvious that most employment is located in the urbanized areas of the cities. Rural and mountain areas are all blue in this map of employment theme meaning the density is low compared to other areas. Recognizing the different geography of where people live and work, suggests that many people maintain an automobile-oriented commuting style.

Single family households are detached and attached residences. Detached units indicate the building does not contain more than one dwelling unit and is surrounded by open space. They include houses, mobile homes and other non-connected units. Attached units share common walls, primarily townhouses and condos. Multi-family households include apartments, condominiums, tri-plexes, four-plexes and any buildings where dwellings have their primary access to a common internal hallway or external corridor and/or common stair. According to figure 9 and figure 10, single family households are more common than multi-family households. Single family households have similar distribution to total population and total households, which tend to locate in Phoenix, Chandler, and other cities. On the other hand, multi-family households distribute less
densely and are recognize more so in Phoenix and Tempe. For instance, one of the red TAZ belongs to ASU Tempe Campus dorm area.

**Ethnicity demographics.**

*Figure 11. All TAZs Ethnic Demographics. Race and Hispanic or Latino Origin—One Race*

Source: U.S. Census Bureau, 2007-2011 American Community Survey, ACS DEMOGRAPHIC AND HOUSING ESTIMATES
Figure 12. All TAZs Ethnic Demographics. Race and Hispanic or Latino Origin—One Race, White

Source: U.S. Census Bureau, 2007-2011 American Community Survey, ACS DEMOGRAPHIC AND HOUSING ESTIMATES
Figure 13. All TAZs Ethnic Demographics. Race and Hispanic or Latino Origin—One Race, Black or African American

Source: U.S. Census Bureau, 2007-2011 American Community Survey, ACS DEMOGRAPHIC AND HOUSING ESTIMATES
Figure 14. All TAZs Ethnic Demographics. White Alone, Not Hispanic or Latino

Source: U.S. Census Bureau, 2007-2011 American Community Survey, ACS DEMOGRAPHIC AND HOUSING ESTIMATES
Figure 15. All TAZs Ethnic Demographics. Hispanic or Latino Origin (of any race)

Source: U.S. Census Bureau, 2007-2011 American Community Survey, ACS
DEMOGRAPHIC AND HOUSING ESTIMATES

Generally speaking, people identified as one race tend to live in Phoenix, Chandler, North Scottsdale, and West Peoria. There is a large red area in South Phoenix. A similar pattern exists for the White (one race) population with a smaller and more south concentration in Phoenix. In contrast, the African-American people residences spread over a smaller range with some density on the South side of Sky Harbor Airport, in North Chandler, and in Southeast Peoria.

The distribution difference between Hispanic and Non-Hispanic residents is obvious. White alone population shows evidence of suburbanization because most of the
red color TAZs are not in the Phoenix downtown area. Also, we may conclude that white and black ethnic groups tend not to live in the same area.

Economic demographics.

Figure 16. All TAZs Employment Demographics, 2008. Public Employment

Source: MAG 2008 Projections for Socioeconomic Input File
Figure 17. All TAZs Employment Demographics, 2008. Retail Employment

Source: MAG 2008 Projections for Socioeconomic Input File
Figure 18. All TAZs Employment Demographics, 2008. Office Employment

Source: MAG 2008 Projections for Socioeconomic Input File
Figure 19. All TAZs Employment Demographics, 2008. Industrial Employment

Source: MAG 2008 Projections for Socioeconomic Input File

Public employment refers to the land use of government or related lands such as courts, state and county complexes, city offices, water treatment facilities, etc. (MAG). We can see from figure 16 that limited public employment exists in our study area except the Luke Air Force Base and some minor concentrated TAZs scatter across the City of Phoenix. Retail employment has the largest work base among the four types of employment. Retail employment refers to the jobs in convenience stores, big box retailers, strip commercial, car dealers and shopping malls as well as other services provided on retail land such as banks and recruiting offices (MAG). Office employment, such as jobs in business parks and office buildings, has a south-north corridor shape.
distribution with some dense TAZs in Phoenix and around airports. Industrial employment supports manufacturing, extraction and processing of raw materials. Most of the industrial employment is located outside cities. It also surrounds both Phoenix Sky Harbor Airport and the Scottsdale Airport.

*Figure 20. All TAZs Income Demographics, 2008. Lowest Income Quintile*

Source: MAG 2008 Projections for Socioeconomic Input File
Figure 21. All TAZs Income Demographics, 2008. Low Income Quintile

Source: MAG 2008 Projections for Socioeconomic Input File
The spatial distribution of lower income households is similar with each other, according to the three figures above. North Phoenix, North to Interstate 10 inside Phoenix, Avondale, etc. is where lower income populations seems to reside. Such distribution is similar to that of the Hispanic population, to some extent.

**Mapping Analysis**

Now we have discussed where different groups of people are and where the majority of jobs are in the Phoenix Metropolitan Area. The next step is to discuss the accessibility analysis which takes three major procedures as previously discussed. The first step is to calculate accessibility measures for each TAZ, which is done by summing
up total population and employment of the “neighborhood” for each TAZ. From there, the same accessibility calculations were carried out on three different travel modes—walking, park and ride, and kiss and ride. Since the home-to-transit station trip is the first part of the entire origin-to-destination trip, the total travel time will vary along with the home-to-transit station time. Accordingly, the accessibility calculation may end up with different TAZ “neighborhoods” because of different home-to-transit station travel modes. Therefore, in the results we have categories of Walking Accessibility, Park-n-Ride Accessibility, and Kiss-n-Ride Accessibility. Further, each travel mode includes a 30 minute sub-category and a 45 minutes sub-category, such as a 30 minutes Walking Accessibility, and a 45 minutes Park-and-Ride Accessibility.

The second procedure is the comparison analysis of the period before the light rail and after the light rail was built. Before proceeding on to comparing, we calculate, under each sub-category described above, non-light rail accessibility and post-light rail accessibility. For instance, there are maps of Non-Light Rail 30 Minute Walking Accessibility, Post-Light Rail 45 minute and Park-and-Ride Accessibility, etc. The diagram below shows the mapping organization, with Walking as an example. The same mapping organization applies to Park-and-Ride and Kiss-and-Ride.
The comparison analysis is comprised of three aspects: basic accessibility which measures the accessibility of the non-light rail period, the “difference” which results from “with light rail accessibility” minus “non-light rail accessibility”, and “percent change” which takes “difference” divided by “non-light rail accessibility”. All of the accessibility categories for each travel mode have now been introduced. Furthermore, when collecting job accessibility measures for each TAZ, we sum up not only the number of all employment in the “neighborhood” but also the numbers of the different types of employments—public employment, retail employment, office employment, and industrial employment. In sum, each travel mode category contains 60 maps in which each map has a specific topic, such as “Non-light rail walking 30 minutes accessibility-public employment”.

With the results from the comparison analysis, we can understand what a difference the existence of the light rail has made on job accessibility for the TAZs.
However, we still need the third step to find out which demographic group is benefiting from the increase of job accessibility.

In the following paragraphs, the findings from each step of the analysis will be discussed. Results will now be presented from one travel mode—walking accessibility with both 30 and 45 minutes time limit. The reason for doing this lies in the fact that both the 2007 pre-light rail and the 2011 on-board surveys showed that most (around 90%) accessed transit (both light rail and bus) by walking (ETC Institute, 2011 p. 55).

**45 minutes, walking, base maps of accessibility (non-light rail).** The Figures below illustrate accessibility measures of TAZs of different employment types.

The first map shows the total population of each TAZ “neighborhood”. The darker the color the larger population is reachable by the given TAZ. From Figure 24 we can tell TAZs of Phoenix, Mesa, and Glendale have better population accessibility. Figure 25 shows the accessible employment opportunities of each TAZ. Apparently, TAZs in South Phoenix, West Mesa, and Tempe had better employment accessibility before the Light Rail was built. The black TAZs can reach more than 700,000 jobs by walking to the stations and taking public transit. This is probably because the City of Phoenix and City of Tempe have better public services. For example, as the host city for the biggest campus of ASU, Tempe maintains a free bus system named “Orbit” which has five routes that serve the city’s residential areas and connect them to local destinations such as shopping areas, other neighborhoods, major bus routes, schools and multi-generational centers (City of Tempe website). Public employment has a similar spatial pattern as that of total employment accessibility but with a smaller concentration.
Black colored TAZs can reach more than 100,000 of public employment opportunities. Other classes of TAZs lie around the densest class like circles. Besides sufficient public transit services, Phoenix and Tempe also have their public jobs at this area, such as the City Hall of the City of Tempe which is located across the street from the Tempe transit center, which makes it easier for government officers to commute by bus. When it comes to retail employment, we can see a wider range of areas that have relatively high job accessibility by being in the first and second classes. Areas covering South Scottsdale, West Mesa, Tempe, and North Chandler are where retail employment is most accessible by TAZs. Perhaps this is due to some of the big shopping malls in the area, such as Scottsdale Fashion Square, Arizona Mills Mall, and Chandler Fashion Square, which makes the TAZs in this area able to achieve more retail employment.
Figure 24. 45 Min, Walking, Non-LRT. Total Population Accessibility.

Source: Data from MAG. Regional transportation model outputs, 2008 and post-processed by A. Golub.
Figure 25. 45 Min, Walking, Non-LRT. Total Employment Accessibility.

Source: Data from MAG. Regional transportation model outputs, 2008 and post-processed by A. Golub.
Figure 26. 45 Min, Walking, Non-LRT. Public Employment Accessibility.

Source: Data from MAG. Regional transportation model outputs, 2008 and post-processed by A. Golub.
Figure 27. 45 Min, Walking, Non-LRT. Retail Employment Accessibility.

Source: Data from MAG. Regional transportation model outputs, 2008 and post-processed by A. Golub.
Figure 28. 45 Min, Walking, Non-LRT. Office Employment Accessibility.

Source: Data from MAG. Regional transportation model outputs, 2008 and post-processed by A. Golub.
Similarly, TAZs that have higher office employment accessibility locate where there are more office jobs. The same rule may apply to the industrial employment accessibility too—high accessibility resides near Phoenix Sky Harbor International Airport. Notice that all the accessibility distributions have their concentration around the core of the study area which is the southern half of Phoenix, Tempe, the west part of Mesa, and the north part of Chandler, which is possibly caused by the situation that these cities tend to have better public transit than others.
**Differences in access.** This part of the research is based on the accessibility results of before-LRT and after-LRT periods.

The difference in accessibility is calculated by subtracting the “before” from the “after” where the exact difference in the number of people or jobs that are reachable is demonstrated. Difference figures can either be positive or negative; respectively meaning the higher or lower accessibility after the LRT started operation. TAZs that are white represent those have little or no change with light rail. These areas have had little to no influence by the light rail.

![Figure 30. 45 Min, Walking, Difference. Total Population Accessibility.](source)

Source: Data from MAG. Regional transportation model outputs, 2008 and post-processed by A. Golub.
Figure 31. 45 Min, Walking, Difference. Total Employment Accessibility.

Source: Data from MAG. Regional transportation model outputs, 2008 and post-processed by A. Golub.
Figure 32. 45 Min, Walking, Difference. Public Employment Accessibility.

Source: Data from MAG. Regional transportation model outputs, 2008 and post-processed by A. Golub.
Figure 33. 45 Min, Walking, Difference. Retail Employment Accessibility.

Source: Data from MAG. Regional transportation model outputs, 2008 and post-processed by A. Golub.
Figure 34. 45 Min, Walking, Difference. Office Employment Accessibility.

Source: Data from MAG. Regional transportation model outputs, 2008 and post-processed by A. Golub.
Maps in this group suggest that the spatial pattern with the most drastic changes occur along the light rail line. Specifically, public employment accessibility changes more than any other type of employment because its map shows the largest area that has increased over 20,000 office jobs all the way from the starting point of light rail in Phoenix to the ending point in Mesa. Retail employment experiences its biggest change near Papago Park. Office and Industrial employment accessibility, instead, increased most along the part of light rail that goes into West Mesa.
**Percent change of accessibility.** The percentage of change of the original accessibility is displayed below.

The value of percent change is calculated by dividing the difference figure by the accessibility measure from the before-LRT period. Percent change tends to discover TAZs’ elasticity in response to light rail.

![45 min, Walking, Percent Change. Total Population Accessibility](image)

*Figure 36. 45 Min, Walking, Percent Change. Total Population Accessibility.*

Source: Data from MAG. Regional transportation model outputs, 2008 and post-processed by A. Golub.
Figure 37. 45 Min, Walking, Percent Change. Total Employment Accessibility.

Source: Data from MAG. Regional transportation model outputs, 2008 and post-processed by A. Golub.
Figure 38. 45 Min, Walking, Percent Change. Public Employment Accessibility.

Source: Data from MAG. Regional transportation model outputs, 2008 and post-processed by A. Golub.
Figure 39. 45 Min, Walking, Percent Change. Retail Employment Accessibility.

Source: Data from MAG. Regional transportation model outputs, 2008 and post-processed by A. Golub.
Figure 40. 45 Min, Walking, Percent Change. Office Employment Accessibility.

Source: Data from MAG. Regional transportation model outputs, 2008 and post-processed by A. Golub.
The employment in general has the biggest change in the west end of the light rail line. Only office employment has a similar pattern for its percent change of accessibility. For industrial employment, two concentrations of the highest percent change areas are at the two terminal areas of light rail line. Retail employment has its biggest change areas at near Papago Park. Public employment does not change a lot along the light rail line but also has an area with a significant amount of change in Northern Phoenix.
Statistical Analysis of Disparities in Access by Race and Income

In this chapter we incorporate demographic aspects into the job accessibility analysis, aiming to answer the question: do minority or lower income population benefit from light rail in terms of job accessibility? Following the same framework, this part of the research also contains two parts due to two time limits—30 and 45 minutes. In the 45 minute portion, three correlation tests were conducted to check for light rail’s impact on accessibility of different ethnic and income groups under the base accessibility (before light rail), difference in accessibility between the before and after periods, and percent change in accessibility.

All of the results from the correlation studies are statistically significant at p = 0.01 level. Specifically, the correlation study presents job accessibility for four demographic groups—Hispanic, non-Hispanic, low-income, and non-low-income, categorized by type of employment. In addition, for each type of employment we calculate the average accessibility of total population to stand for the reference accessibility record.
Figure 42. 45 Min, Walking, Non-LRT. Accessibility by race and income.

Note: The differences in means between Hispanic and Non-Hispanic and between Low-Income and Non-Low-Income are statistically significant at p = 0.01 level.

This histogram is about the 45 minute base accessibility. It is clear that, on average, more Hispanic and low-income populations are accessible by TAZs and the same trend is shown in employment accessibilities. In public employment accessibility, Hispanic and low-income people have better accessibility than other groups but the advantage is not very significant. Retail employment accessibility is almost equal among different demographic groups. Low-income people have the best office employment accessibility among the five groups and Hispanic people are the most advantaged in industrial jobs.
Figure 43: 45 Min, Walking, Difference. Accessibility by race and income.

Note: The differences in means between Hispanic and Non-Hispanic and between Low-Income and Non-Low-Income are statistically significant at $p = 0.01$ level.

In this correlation test about the accessibility differences, Hispanic and low-income people present a more significant advantage than non-Hispanic and non-low-income population. In the total employment category, low-income people have almost twice the accessibility of non-low-income people and have increased around 8,000 more jobs than the change of average population. Similarly, the low-income group has the biggest increase in all of the three employment breakdowns except for office employment.
Figure 44. 45 Min, Walking, Percent Change (With-LRT). Accessibility by race and income.

Note: The differences in means between Hispanic and Non-Hispanic and between Low-Income and Non-Low-Income are statistically significant at $p = 0.01$ level.

The correlation test for percent change in accessibility looks a great deal different than the diagrams presented before because percentage change disregards the numerical base, which makes the “All” column lowest. However, a similar trend can still be applied to this test in that public employment and office employment show the biggest percent change. In office employment, Hispanic people increased their job accessibility by almost 7 percent. Office employment creates the highest amounts for Hispanic and low-income groups’ percent increase in job accessibility. Throughout all types of employment, Hispanic and low-income populations are more responsive to light rail than other groups, in terms of accessibility.
Comparison of 45 and 30 minutes tests. The 45 minutes base case correlation test has the same characteristics as that of 30 minutes.

However, the accessibility difference correlation test starts to show an interesting new trend. From the histogram above, it shows that the difference of the number of accessible destinations now has a wider range which is more than double the variation of 30 minutes test. This is because the longer time limit allows a wider reachable area. Interestingly, for office employment, low-income people’s increase is lower than that of the Hispanic people, which cannot be explained by the bigger numerical base of 45 minutes. Other types of employment also have similar trends as described for the 30 minutes accessibility difference test.

In this percent change correlation test, Hispanic and low-income groups still have higher performance than other groups. Different from the 30 minutes percent change test, Hispanic tends to increase more than the low-income group. Besides, Hispanic people’s percent change is almost twice that of non-Hispanic people and low-income people’s percent change is also around 40 percent more than the non-low-income people.

Conclusion

In this study we try to find out the impact of the Phoenix light rail on job accessibility and whether the impact has brought more benefits to minority and lower-income population in the study area. The results are significant. Mapping of the spatial pattern of the light rail’s impact on job accessibility shows that most TAZs have increased accessibility after the light rail and most of the changes have occurred along the light rail line. It is possible to achieve a preliminary conclusion that light rail has
improved the job accessibility of areas that fall within a certain distance around the light rail line. However, we do not conduct further analysis on the exact length of this distance. This may serve as a future topic of study. The more promising conclusions come from the results of the correlation tests of accessibility and demographic groups. In this test, we aimed to find out whether minority and lower-income population are able to benefit more than other demographic groups in terms of job accessibility. This statistical analysis does not include geographic aspects of demography and calculate the average values to represent other situations. Both the results from the 30 and 45 minutes correlation tests show that Hispanic and lower-income groups enjoy the highest change and highest percent change among all demographic groups and employment categories. There is a slight difference in which changes the most, Hispanic or lower-income depending on the time period. The 30 minutes tests result in the lower-income group having the most significant change among the two groups. The 45 minute tests result in the Hispanic group having the most significant change over the lower-income group. Therefore, our hypothesis that the light rail does increase the job accessibility of minority and lower-income people more than other demographic groups is correct. Future research should incorporate the demographic geography to account for spatial aspects. Transportation and equity have been in the purview of American's since the 1960s when the Montgomery bus boycott signified the start of a series of civil right movements. Transportation related laws and policies from different levels of governments have come out since then to promote social equity in the realm of transportation. Transportation planning methodology has been questioned as well and has been encouraged to provide more equal provisions for the population. However, for many years, transportation planners were
using cost-benefit based planning tools to create transportation models, which led to an automobile-oriented transportation style. On the other hand, the development of a transportation system, such as improving mobility by providing more road networks, will ultimately change the land-use pattern. With more and more people moving into the outskirts of cities, some businesses and industries are also moving to the suburbs. Suburbanization has created many basic level jobs but is not providing enough housing opportunities for people who work at these jobs. Identifying this phenomenon, a spatial mismatch hypothesis has been put forward by Kain some 50 years ago. This hypothesis contends that the long distance between the places where lower-income and minority people work and live can cause significant trouble for their daily commuting. In addition, suburbs do not usually have sufficient public transit systems connecting to the central city and affordable housing for these workers. Additionally, cars are not always affordable for low-income and minority populations. Considering these two major situations minority and lower-income people face, researchers have raised a fierce debate on what is a more appropriate solution for the mismatch problem—public transit versus automobiles. It is still difficult to decide which way to go but at least we can provide more evidence to decision makers and help them make effective options to tackle the social inequality issue in transportation.

Light rail has become popular around the world. There are a lot of light rail projects in developing countries and many middle-sized cities in the U.S. Phoenix opened its first 20 mile light rail line in the end of 2008. Since then, ridership of Phoenix light rail has consistently been more than expected. In the light rail literature, many focus on the relationship between the light rail line and nearby property values. Few works have
shed light on the light rail impacts on the social equity problem. This research on the Phoenix light rail is innovative in the literature and has discovered important facts about light rail’s social function—increasing job accessibility for disadvantaged populations. In addition, future studies can continue on this topic but also focus on the new Light Rail line which not only contains the Phoenix and—Tempe portions but also the extension into the City of Mesa.

This study will provide evidences for decision makers when considering light rail projects as part of their transportation improvement development. With less green house gas (GHG) emissions, light rail can effectively increase job accessibility of minority and lower-income populations by public transit and mitigate the inequality issue to a certain degree.

References


Maricopa Association of Governments. *Information services.*
http://www.azmag.gov/Information_Services/


Phoenix Sky Harbor International Airport. *Airport facts.*
http://skyharbor.com/about/airportFacts.html


Rast, J. (2004). Transportation equity and access to jobs in metropolitan Milwaukee. 5 University of Wisconsin-Milwaukee Center for Economic Development.


U.S. Census Bureau. SELECTED ECONOMIC CHARACTERISTICS – 2010 American Community Survey 1-Year Estimates, U.S. Census Bureau


APPENDIX

RESULTS FROM ACCESSIBILITY ANALYSIS AND DIFFERENCE ANALYSIS
Accessibility Analysis
Walking, 30 minutes, Non-LRT

Figure 45. Total Population Accessibility, Walking, 30 minutes, Non-Light Rail
Source: Data from MAG. Regional transportation model outputs, 2008 and post-processed by A. Golub.
Figure 46. Total Employment Accessibility, Walking, 30 minutes, Non-Light Rail
Source: Data from MAG. Regional transportation model outputs, 2008 and post-processed by A. Golub.
Figure 47. Public Employment Accessibility, Walking, 30 minutes, Non-Light Rail

Source: Data from MAG. Regional transportation model outputs, 2008 and post-processed by A. Golub.
Figure 48. Retail Employment Accessibility, Walking, 30 minutes, Non-Light Rail
Source: Data from MAG. Regional transportation model outputs, 2008 and post-processed by A. Golub.
Figure 49. Office Employment Accessibility, Walking, 30 minutes, Non-Light Rail
Source: Data from MAG. Regional transportation model outputs, 2008 and post-processed by A. Golub.
Figure 50. Industrial Employment Accessibility, Walking, 30 minutes, Non-Light Rail

Source: Data from MAG. Regional transportation model outputs, 2008 and post-processed by A. Golub.
Walking, 30 minutes, Difference in Accessibility

Figure 51. Difference in Total Population Accessibility, Walking, 30 minutes

Source: Data from MAG. Regional transportation model outputs, 2008 and post-processed by A. Golub.
Figure 52. Difference in Total Employment Accessibility, Walking, 30 minutes

Source: Data from MAG. Regional transportation model outputs, 2008 and post-processed by A. Golub.
Figure 53. Difference in Public Employment Accessibility, Walking, 30 minutes

Source: Data from MAG. Regional transportation model outputs, 2008 and post-processed by A. Golub.
Figure 54. Difference in Retail Employment Accessibility, Walking, 30 minutes

Source: Data from MAG. Regional transportation model outputs, 2008 and post-processed by A. Golub.
Figure 55. Difference in Office Employment Accessibility, Walking, 30 minutes

Source: Data from MAG. Regional transportation model outputs, 2008 and post-processed by A. Golub.
Figure 56. Difference in Industrial Employment Accessibility, Walking, 30 minutes

Source: Data from MAG. Regional transportation model outputs, 2008 and post-processed by A. Golub.
Walking, 30 minutes, Percent Change in Accessibility

Figure 57. Percent Change in Total Population Accessibility, Walking, 30 minutes

Source: Data from MAG. Regional transportation model outputs, 2008 and post-processed by A. Golub.
Figure 58. Percent Change in Total Employment Accessibility, Walking, 30 minutes

Source: Data from MAG. Regional transportation model outputs, 2008 and post-processed by A. Golub.
Figure 59. Percent Change in Public Employment Accessibility, Walking, 30 minutes

Source: Data from MAG. Regional transportation model outputs, 2008 and post-processed by A. Golub.
Figure 60. Percent Change in Retail Employment Accessibility, Walking, 30 minutes

Source: Data from MAG. Regional transportation model outputs, 2008 and post-processed by A. Golub.
Figure 61. Percent Change in Office Employment Accessibility, Walking, 30 minutes

Source: Data from MAG. Regional transportation model outputs, 2008 and post-processed by A. Golub.
Figure 62. Percent Change in Industrial Employment Accessibility, Walking, 30 minutes

Source: Data from MAG. Regional transportation model outputs, 2008 and post-processed by A. Golub.
Park-and-Ride, 30 minutes, Non-LRT

Figure 63. Total Population Accessibility, PNR, 30 minutes, Non-Light Rail

Source: Data from MAG. Regional transportation model outputs, 2008 and post-processed by A. Golub.
Figure 64. Total Employment Accessibility, PNR, 30 minutes, Non-Light Rail

Source: Data from MAG. Regional transportation model outputs, 2008 and post-processed by A. Golub.
Figure 65. Public Employment Accessibility, PNR, 30 min, Non-Light Rail

Source: Data from MAG. Regional transportation model outputs, 2008 and post-processed by A. Golub.
Figure 66. Retail Employment Accessibility, PNR, 30 min, Non-LRT

Source: Data from MAG. Regional transportation model outputs, 2008 and post-processed by A. Golub.
Figure 67. Office Employment Accessibility, PNR, 30 min, Non-LRT

Source: Data from MAG. Regional transportation model outputs, 2008 and post-processed by A. Golub.
Figure 68. Industrial Employment Accessibility, PNR, 30 min, Non-LRT

Source: Data from MAG. Regional transportation model outputs, 2008 and post-processed by A. Golub.
Figure 69. Difference in Total Population Accessibility, PNR, 30 min

Source: Data from MAG. Regional transportation model outputs, 2008 and post-processed by A. Golub.
Figure 70. Difference in Total Employment Accessibility, PNR, 30 min

Source: Data from MAG. Regional transportation model outputs, 2008 and post-processed by A. Golub.
Figure 71. Difference in Public Employment Accessibility, PNR, 30 min

Source: Data from MAG. Regional transportation model outputs, 2008 and post-processed by A. Golub.
Figure 72. Difference in Retail Employment Accessibility, PNR, 30 min

Source: Data from MAG. Regional transportation model outputs, 2008 and post-processed by A. Golub.
Figure 73. Difference in Office Employment Accessibility, PNR, 30min

Source: Data from MAG. Regional transportation model outputs, 2008 and post-processed by A. Golub.
Figure 74. Difference in Industrial Employment Accessibility, PNR, 30 min

Source: Data from MAG. Regional transportation model outputs, 2008 and post-processed by A. Golub.
Park-and-Ride, 30 minutes, Percent Change in Accessibility

Figure 75. Percent Change in Total Population Accessibility, PNR, 30

Source: Data from MAG. Regional transportation model outputs, 2008 and post-processed by A. Golub.
Figure 76. Percent Change in Total Employment Accessibility, PNR, 30

Source: Data from MAG. Regional transportation model outputs, 2008 and post-processed by A. Golub.
Figure 77. Percent Change in Public Employment Accessibility, PNR, 30

Source: Data from MAG. Regional transportation model outputs, 2008 and post-processed by A. Golub.
Figure 78. Percent Change in Retail Employment Accessibility, PNR, 30

Source: Data from MAG. Regional transportation model outputs, 2008 and post-processed by A. Golub.
Figure 79. Percent Change in Office Employment Accessibility, PNR, 30 min
Source: Data from MAG. Regional transportation model outputs, 2008 and post-processed by A. Golub.
Figure 80. Percent Change in Industrial Employment Accessibility, PNR, 30min

Source: Data from MAG. Regional transportation model outputs, 2008 and post-processed by A. Golub.
Park-and-Ride, 45 minutes, Non-LRT

Figure 81. Total Population Accessibility, PNR, 45 min, Non-LRT

Source: Data from MAG. Regional transportation model outputs, 2008 and post-processed by A. Golub.
Figure 82. Total Employment Accessibility, PNR, 45 min, Non-LRT

Source: Data from MAG. Regional transportation model outputs, 2008 and post-processed by A. Golub.
Figure 83. Public Employment Accessibility, PNR, 45 min, Non-LRT

Source: Data from MAG. Regional transportation model outputs, 2008 and post-processed by A. Golub.
Figure 84. Retail Employment Accessibility, PNR, 45 min, Non-LRT

Source: Data from MAG. Regional transportation model outputs, 2008 and post-processed by A. Golub.
Figure 85. Office Employment Accessibility, PNR, 45 min, Non-LRT

Source: Data from MAG. Regional transportation model outputs, 2008 and post-processed by A. Golub.
Figure 86. Industrial Employment Accessibility, PNR, 45 min, Non-LRT

Source: Data from MAG. Regional transportation model outputs, 2008 and post-processed by A. Golub.
Figure 87. Difference in Total Population Accessibility, PNR, 45 min

Source: Data from MAG. Regional transportation model outputs, 2008 and post-processed by A. Golub.
Figure 88. Difference in Total Employment Accessibility, PNR, 45 min

Source: Data from MAG. Regional transportation model outputs, 2008 and post-processed by A. Golub.
Figure 89. Difference in Public Employment Accessibility, PNR, 45 min

Source: Data from MAG. Regional transportation model outputs, 2008 and post-processed by A. Golub.
Figure 90. Difference in Retail Employment Accessibility, PNR, 45 min

Source: Data from MAG. Regional transportation model outputs, 2008 and post-processed by A. Golub.
Figure 91. Difference in Office Employment Accessibility, PNR, 45 min

Source: Data from MAG. Regional transportation model outputs, 2008 and post-processed by A. Golub.
Figure 92. Difference in Industrial Employment Accessibility, PNR, 45 min

Source: Data from MAG. Regional transportation model outputs, 2008 and post-processed by A. Golub.
Figure 93. Percent Change in Total Population Accessibility, PNR, 45 min

Source: Data from MAG. Regional transportation model outputs, 2008 and post-processed by A. Golub.
Figure 94. Percent Change in Total Employment Accessibility, PNR, 45 min

Source: Data from MAG. Regional transportation model outputs, 2008 and post-processed by A. Golub.
Figure 95. Percent Change in Public Employment Accessibility, PNR, 45 min

Source: Data from MAG. Regional transportation model outputs, 2008 and post-processed by A. Golub.
Figure 96. Percent Change in Retail Employment Accessibility, PNR, 45 min

Source: Data from MAG. Regional transportation model outputs, 2008 and post-processed by A. Golub.
Figure 97. Percent Change in Office Employment Accessibility, PNR, 45 min

Source: Data from MAG. Regional transportation model outputs, 2008 and post-processed by A. Golub.
Figure 98. Percent Change in Industrial Employment Accessibility, PNR, 45 min

Source: Data from MAG. Regional transportation model outputs, 2008 and post-processed by A. Golub.
Kiss-and-Ride, 30 minutes, Non-LRT

Figure 99. Total Population Accessibility, KNR, 30 min, Non-LRT

Source: Data from MAG. Regional transportation model outputs, 2008 and post-processed by A. Golub.
Figure 100. Total Employment Accessibility, KNR, 30 min, Non-LRT

Source: Data from MAG. Regional transportation model outputs, 2008 and post-processed by A. Golub.
Figure 101. Public Employment Accessibility, KNR, 30 min, Non-LRT

Source: Data from MAG. Regional transportation model outputs, 2008 and post-processed by A. Golub.
Figure 102. Retail Employment Accessibility, KNR, 30 min, Non-LRT

Source: Data from MAG. Regional transportation model outputs, 2008 and post-processed by A. Golub.
Figure 103. Office Employment Accessibility, KNR, 30 min, Non-LRT

Source: Data from MAG. Regional transportation model outputs, 2008 and post-processed by A. Golub.
Figure 104. Industrial Employment Accessibility, KNR, 30 min, Non-LRT

Source: Data from MAG. Regional transportation model outputs, 2008 and post-processed by A. Golub.
Kiss-and-Ride, 30 minutes, Difference in Accessibility

Figure 105. Difference in Total Population Accessibility, KNR, 30 min

Source: Data from MAG. Regional transportation model outputs, 2008 and post-processed by A. Golub.
Figure 106. Difference in Total Employment Accessibility, KNR, 30 min

Source: Data from MAG. Regional transportation model outputs, 2008 and post-processed by A. Golub.
Figure 107. Difference in Public Employment Accessibility, KNR, 30 min

Source: Data from MAG. Regional transportation model outputs, 2008 and post-processed by A. Golub.
Figure 108. Difference in Retail Employment Accessibility, KNR, 30 min

Source: Data from MAG. Regional transportation model outputs, 2008 and post-processed by A. Golub.
Figure 109. Difference in Office Employment Accessibility, KNR, 30 min

Source: Data from MAG. Regional transportation model outputs, 2008 and post-processed by A. Golub.
Figure 110. Difference in Industrial Employment Accessibility, KNR, 30 min

Source: Data from MAG. Regional transportation model outputs, 2008 and post-processed by A. Golub.
Kiss-and-Ride, 30 minutes, Percent Change in Accessibility

Figure 111. Percent Change in Total Population Accessibility, KNR, 30 min

Source: Data from MAG. Regional transportation model outputs, 2008 and post-processed by A. Golub.
Figure 112. Percent Change in Total Employment Accessibility, KNR, 30 min

Source: Data from MAG. Regional transportation model outputs, 2008 and post-processed by A. Golub.
Figure 113. Percent Change in Public Employment Accessibility, KNR, 30 min

Source: Data from MAG. Regional transportation model outputs, 2008 and post-processed by A. Golub.
Figure 114. Percent Change in Retail Employment Accessibility, KNR, 30 min

Source: Data from MAG. Regional transportation model outputs, 2008 and post-processed by A. Golub.
Figure 115. Percent Change in Office Employment Accessibility, KNR, 30 min

Source: Data from MAG. Regional transportation model outputs, 2008 and post-processed by A. Golub.
Figure 116. Percent Change in Industrial Employment Accessibility, KNR, 30 min
Source: Data from MAG. Regional transportation model outputs, 2008 and post-processed by A. Golub.
Kiss-and-Ride, 45 minutes, Non-LRT

Figure 117. Total Population Accessibility, KNR, 30 min, Non-LRT

Source: Data from MAG. Regional transportation model outputs, 2008 and post-processed by A. Golub.
Figure 118. Total Employment Accessibility, KNR, 45 min, Non-LRT

Source: Data from MAG. Regional transportation model outputs, 2008 and post-processed by A. Golub.
Figure 119. Public Employment Accessibility, KNR, 45 min, Non-LRT

Source: Data from MAG. Regional transportation model outputs, 2008 and post-processed by A. Golub.
Figure 120. Retail Employment Accessibility, KNR, 45 min, Non-LRT

Source: Data from MAG. Regional transportation model outputs, 2008 and post-processed by A. Golub.
Figure 121. Office Employment Accessiblity, KNR, 45 min, Non-LRT

Source: Data from MAG. Regional transportation model outputs, 2008 and post-processed by A. Golub.
Figure 122. Industrial Employment Accessibility, KNR, 45 min, Non-LRT

Source: Data from MAG. Regional transportation model outputs, 2008 and post-processed by A. Golub.
Kiss-and-Ride, 45 minutes, Difference in Accessibility

Figure 123. Difference in Total Population Accessibility, KNR, 45 min

Source: Data from MAG. Regional transportation model outputs, 2008 and post-processed by A. Golub.
Figure 124. Difference in Total Employment Accessibility, KNR, 45 min

Source: Data from MAG. Regional transportation model outputs, 2008 and postprocessed by A. Golub.
Figure 125. Difference in Public Employment Accessibility, KNR, 45 min

Source: Data from MAG. Regional transportation model outputs, 2008 and post-processed by A. Golub.
Figure 126. Difference in Retail Employment Accessibility, KNR, 45 min

Source: Data from MAG. Regional transportation model outputs, 2008 and post-processed by A. Golub.
Figure 127. Difference in Office Employment Accessibility, KNR, 45 min

Source: Data from MAG. Regional transportation model outputs, 2008 and post-processed by A. Golub.
Figure 128. Difference in Industrial Employment Accessibility, KNR, 45 min

Source: Data from MAG. Regional transportation model outputs, 2008 and post-processed by A. Golub.
Kiss-and-Ride, 45 minutes, Percent Change in Accessibility

Figure 129. Percent Change in Total Population Accessibility, KNR, 45 min

Source: Data from MAG. Regional transportation model outputs, 2008 and post-processed by A. Golub.
Figure 130. Percent Change in Total Employment Accessibility, KNR, 45 min

Source: Data from MAG. Regional transportation model outputs, 2008 and post-processed by A. Golub.
Figure 131. Percent Change in Public Employment Accessibility, KNR, 45 min

Source: Data from MAG. Regional transportation model outputs, 2008 and post-processed by A. Golub.
Figure 132. Percent Change in Retail Employment Accessibility, KNR, 45 min

Source: Data from MAG. Regional transportation model outputs, 2008 and post-processed by A. Golub.
Figure 133. Percent Change in Office Employment Accessibility, KNR, 45 min
Source: Data from MAG. Regional transportation model outputs, 2008 and post-processed by A. Golub.
Figure 134. Percent Change in Industrial Employment Accessibility, KNR, 45 min
Source: Data from MAG. Regional transportation model outputs, 2008 and post-processed by A. Golub.
Statistical Analysis of Disparities in Access by Race and Income

Table 1.

Walking, 30 minutes, Non-LRT

<table>
<thead>
<tr>
<th>Average Accessible (Population Weighted)</th>
<th>Population</th>
<th>Employment</th>
<th>Public Employment</th>
<th>Retail Employment</th>
<th>Office Employment</th>
<th>Industrial Employment</th>
</tr>
</thead>
<tbody>
<tr>
<td>All</td>
<td>390,179</td>
<td>193,150</td>
<td>28,387</td>
<td>54,016</td>
<td>49,273</td>
<td>43,120</td>
</tr>
<tr>
<td>Hispanic</td>
<td>428,890</td>
<td>214,508</td>
<td>34,064</td>
<td>54,529</td>
<td>51,718</td>
<td>54,846</td>
</tr>
<tr>
<td>Non-Hispanic</td>
<td>364,516</td>
<td>170,252</td>
<td>23,909</td>
<td>52,248</td>
<td>43,717</td>
<td>33,788</td>
</tr>
<tr>
<td>Low-Income</td>
<td>411,045</td>
<td>213,599</td>
<td>1,801</td>
<td>56,433</td>
<td>56,719</td>
<td>47,980</td>
</tr>
<tr>
<td>Non-Low-Income</td>
<td>369,485</td>
<td>176,354</td>
<td>24,876</td>
<td>52,466</td>
<td>45,196</td>
<td>36,964</td>
</tr>
</tbody>
</table>

(The differences in means between Hispanic and Non-Hispanic and between Low-Income and Non-Low-Income are statistically significant at p = 0.01 level)

Table 2.

Walking, 30 minutes, Difference in Accessibility

<table>
<thead>
<tr>
<th>Average change in Accessible (Population Weighted)</th>
<th>Population</th>
<th>Employment</th>
<th>Public Employment</th>
<th>Retail Employment</th>
<th>Office Employment</th>
<th>Industrial Employment</th>
</tr>
</thead>
<tbody>
<tr>
<td>All</td>
<td>9,403</td>
<td>10,469</td>
<td>1,939</td>
<td>1,648</td>
<td>3,630</td>
<td>2,160</td>
</tr>
<tr>
<td>Hispanic</td>
<td>10,998</td>
<td>12,286</td>
<td>2,152</td>
<td>1,996</td>
<td>4,454</td>
<td>2,348</td>
</tr>
<tr>
<td>Non-Hispanic</td>
<td>6,087</td>
<td>7,211</td>
<td>1,409</td>
<td>1,014</td>
<td>2,501</td>
<td>1,497</td>
</tr>
<tr>
<td>Low-Income</td>
<td>13,077</td>
<td>14,666</td>
<td>2,754</td>
<td>2,290</td>
<td>5,003</td>
<td>3,046</td>
</tr>
<tr>
<td>Non-Low-Income</td>
<td>6,177</td>
<td>7,414</td>
<td>1,444</td>
<td>1,052</td>
<td>2,597</td>
<td>1,549</td>
</tr>
</tbody>
</table>

(The differences in means between Hispanic and Non-Hispanic and between Low-Income and Non-Low-Income are statistically significant at p = 0.01 level)
Table 3.

Walking, 30 minutes, Percent Change in Accessibility

<table>
<thead>
<tr>
<th>Average Percent Change (Population Weighted)</th>
<th>Population</th>
<th>Employment</th>
<th>Public Employment</th>
<th>Retail Employment</th>
<th>Office Employment</th>
<th>Industrial Employment</th>
</tr>
</thead>
<tbody>
<tr>
<td>All</td>
<td>2.0%</td>
<td>3.1%</td>
<td>4.3%</td>
<td>2.3%</td>
<td>4.5%</td>
<td>3.0%</td>
</tr>
<tr>
<td>Hispanic</td>
<td>2.3%</td>
<td>3.7%</td>
<td>4.5%</td>
<td>2.8%</td>
<td>5.7%</td>
<td>3.2%</td>
</tr>
<tr>
<td>Non-Hispanic</td>
<td>1.4%</td>
<td>2.2%</td>
<td>3.4%</td>
<td>1.4%</td>
<td>3.1%</td>
<td>2.3%</td>
</tr>
<tr>
<td>Low-Income</td>
<td>2.8%</td>
<td>4.3%</td>
<td>5.9%</td>
<td>3.1%</td>
<td>6.0%</td>
<td>4.1%</td>
</tr>
<tr>
<td>Non-Low-Income</td>
<td>1.4%</td>
<td>2.3%</td>
<td>3.5%</td>
<td>1.4%</td>
<td>3.3%</td>
<td>2.3%</td>
</tr>
</tbody>
</table>

(The differences in means between Hispanic and Non-Hispanic and between Low-Income and Non-Low-Income are statistically significant at p = 0.01 level)

Table 4.

Walking, 45 minutes, Non-LRT

<table>
<thead>
<tr>
<th>Average Accessible (Population Weighted)</th>
<th>Population</th>
<th>Employment</th>
<th>Public Employment</th>
<th>Retail Employment</th>
<th>Office Employment</th>
<th>Industrial Employment</th>
</tr>
</thead>
<tbody>
<tr>
<td>All</td>
<td>778732</td>
<td>404245</td>
<td>60191</td>
<td>108509</td>
<td>106845</td>
<td>89762</td>
</tr>
<tr>
<td>Hispanic</td>
<td>841457</td>
<td>440039</td>
<td>69047</td>
<td>109832</td>
<td>113195</td>
<td>106321</td>
</tr>
<tr>
<td>Non-Hispanic</td>
<td>730832</td>
<td>365364</td>
<td>52963</td>
<td>104623</td>
<td>96492</td>
<td>75608</td>
</tr>
<tr>
<td>Low-Income</td>
<td>819340</td>
<td>438285</td>
<td>65602</td>
<td>113392</td>
<td>118622</td>
<td>97901</td>
</tr>
<tr>
<td>Non-Low-Income</td>
<td>743308</td>
<td>378529</td>
<td>55317</td>
<td>105621</td>
<td>100076</td>
<td>81006</td>
</tr>
</tbody>
</table>

(The differences in means between Hispanic and Non-Hispanic and between Low-Income and Non-Low-Income are statistically significant at p = 0.01 level)
Table 5.

Walking, 45 minutes, Difference in Accessibility

<table>
<thead>
<tr>
<th>Average change in Accessible (Population Weighted)</th>
<th>Population</th>
<th>Employment</th>
<th>Public Employment</th>
<th>Retail Employment</th>
<th>Office Employment</th>
<th>Industrial Employment</th>
</tr>
</thead>
<tbody>
<tr>
<td>All</td>
<td>24511</td>
<td>22996</td>
<td>3477</td>
<td>4400</td>
<td>7032</td>
<td>5658</td>
</tr>
<tr>
<td>Hispanic</td>
<td>29964</td>
<td>29459</td>
<td>4621</td>
<td>5416</td>
<td>9159</td>
<td>7236</td>
</tr>
<tr>
<td>Non-Hispanic</td>
<td>16188</td>
<td>16282</td>
<td>2403</td>
<td>2917</td>
<td>5215</td>
<td>4009</td>
</tr>
<tr>
<td>Low-Income</td>
<td>32946</td>
<td>30181</td>
<td>4537</td>
<td>5904</td>
<td>9025</td>
<td>7422</td>
</tr>
<tr>
<td>Non-Low-Income</td>
<td>16752</td>
<td>17227</td>
<td>2577</td>
<td>3065</td>
<td>5445</td>
<td>4322</td>
</tr>
</tbody>
</table>

(The differences in means between Hispanic and Non-Hispanic and between Low-Income and Non-Low-Income are statistically significant at p = 0.01 level)

Table 6.

Walking, 45 minutes, Percent Change in Accessibility

<table>
<thead>
<tr>
<th>Average Percent Change (Population Weighted)</th>
<th>Population</th>
<th>Employment</th>
<th>Public Employment</th>
<th>Retail Employment</th>
<th>Office Employment</th>
<th>Industrial Employment</th>
</tr>
</thead>
<tbody>
<tr>
<td>All</td>
<td>2.5%</td>
<td>4.0%</td>
<td>4.2%</td>
<td>3.2%</td>
<td>5.2%</td>
<td>4.3%</td>
</tr>
<tr>
<td>Hispanic</td>
<td>3.1%</td>
<td>5.1%</td>
<td>5.4%</td>
<td>4.0%</td>
<td>6.9%</td>
<td>5.4%</td>
</tr>
<tr>
<td>Non-Hispanic</td>
<td>1.7%</td>
<td>3.0%</td>
<td>3.0%</td>
<td>2.1%</td>
<td>4.0%</td>
<td>3.3%</td>
</tr>
<tr>
<td>Low-Income</td>
<td>3.3%</td>
<td>5.1%</td>
<td>5.3%</td>
<td>4.1%</td>
<td>6.3%</td>
<td>5.5%</td>
</tr>
<tr>
<td>Non-Low-Income</td>
<td>1.8%</td>
<td>3.1%</td>
<td>3.2%</td>
<td>2.2%</td>
<td>4.2%</td>
<td>3.5%</td>
</tr>
</tbody>
</table>

(The differences in means between Hispanic and Non-Hispanic and between Low-Income and Non-Low-Income are statistically significant at p = 0.01 level)
Figure 135. Accessibility by race and income, Walking, 30 min, Non-LRT

Note: The differences in means between Hispanic and Non-Hispanic and between Low-Income and Non-Low-Income are statistically significant at $p = 0.01$ level.
Figure 136. Difference in accessibility by race and income, Walking, 30 min

Note: The differences in means between Hispanic and Non-Hispanic and between Low-Income and Non-Low-Income are statistically significant at $p = 0.01$ level.
Figure 137. Percent change in accessibility by race and income, Walking, 30 min

Note: The differences in means between Hispanic and Non-Hispanic and between Low-Income and Non-Low-Income are statistically significant at $p = 0.01$ level.