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Transportation Impact of Transitways:
A Case Study of Hiawatha Light Rail Transit in Minneapolis

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16. Abstract (Limit: 250 words)

The Metropolitan Council in the Minneapolis-St. Paul metropolitan area (Twin Cities) aims to greatly increase transit ridership in the next two decades. A network of transitways is an essential component to achieve the ridership goal. Since transitways represent significant infrastructure investments from federal, state, and local governments, the public and planners are interested in their ridership bonus. This study investigated transportation impact of the Hiawatha light rail transit (LRT) using a 2011 dataset collected in the Twin Cities. By employing a match-pair cross-sectional design, we surveyed residents living in the middle section of the Hiawatha LRT corridor and those in two urban control corridors and two suburban control corridors in the region. We first explored the reasons that motivated residents moving into the LRT corridor (or residential preferences) and their connections with transit use. Then we employed a propensity score matching approach to study the impact of Hiawatha LRT on transit use for residents who moved to the corridor before its opening and for those who moved after its opening. Finally, we tested the carryover effect of the LRT and built environment effect on active travel: walking to stores and strolling. The study produced interesting results and offered important implications for land use and transportation policies associated with light rail transit.

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Transportation Impact of Transitways: A Case Study of Hiawatha Light Rail Transit in Minneapolis

Final Report

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EXECUTIVE SUMMARY

In its 2030 Transportation Policy Plan, the Metropolitan Council in the Minneapolis-St. Paul metropolitan area (Twin Cities) aims to double the 2004 transit ridership by 2030. Transitway, which has been touted as an effective way to increase ridership and stimulate economic development, is an essential component to achieve this goal. This study attempts to explore transportation benefits of a transitway line in the Twin Cities.

This study employs a matched-pair cross-sectional design to compare travel behavior of residents in the Hiawatha light rail transit (LRT) corridor to those in similar corridors without nearby transitways. For the Hiawatha corridor, we focus on residents living within about ½ mile of LRT stations in the middle section of the Hiawatha Line (from Lake Street to 50th Street). About 1,300 survey respondents answered questions about their residential preferences and perceptions, daily travel patterns, travel preferences, and demographics. For each respondent, a set of geospatial variables were constructed to measure density, land use mix, business activity, and transportation facilities within ¼, ½, and 1 mile of their home.

The first component of the study focuses on residents who moving into their neighborhoods after 2004 when the Hiawatha line started its revenue service. We explore residents' motivations for choosing their current neighborhoods and their connections with transit use. We find that there are few differences in residential preferences between urban residents who live close to or far from the LRT, except their preferences for transit access and quality. The models show that transit preferences are significantly associated with the characteristics of transportation-disadvantaged people and people's intrinsic affection toward transit. There are no significant differences in demographics and transit use between Hiawatha and urban control residents.

The second component quantifies the impact of the Hiawatha LRT on transit use. LRT increases transit use for commute and non-work trips among residents who chose to stay in the Hiawatha corridor after the LRT opened. But the increase is far smaller than those suggested by previous studies. Residents moving into the Hiawatha corridor after its opening use transit as often as new residents in similar urban neighborhoods.

The third component evaluates the relationship between LRT and utilitarian and recreational pedestrian travel. Proximity to commercial areas, adequate density, and a continuous street grid are significant predictors for the frequency of walking to a store. The presence of LRT in this study is not significant after controlling for the built environment, suggesting no unique impact on utilitarian walking trips. Lack of a driver license and lower-income respondents were still predictive of increased utilitarian pedestrian trips even after controlling for preferences, perceptions, and the built environment. Street pattern is found to be significantly associated with strolling frequency whereas the Hiawatha LRT is not.

1. INTRODUCTION

Rail transit has been touted as an effective way to increase ridership, mitigate traffic congestion, and stimulate economic development (Cervero, Murphy et al. 2004; Litman 2005). Since many politicians and planners believe that rail transit can address their urban problems, they are enthusiastic to rail transit in the U.S. The public also offer strong support to rail investments (Staff 2013). Accordingly, more than a dozen rail transit facilities (including light rail, streetcar, and passenger rail) have started services since 2000. For Fiscal Year 2013, about three dozen projects (including bus rapid transit) have received or been pursuing federal funding from New Starts, a discretionary program of the Federal Transit Administration which supports capital investment of fixed guideways (FTA 2012). Some cities explored alternative funding venues to support rail infrastructure development. For instance, Houston METRORail relied on entirely local funding; public-private partnership was adopted for the Airport Max project in Portland.

In its 2030 Transportation Policy Plan, the Metropolitan Council in the Minneapolis-St. Paul metropolitan area (Twin Cities) aims to double the 2004 transit ridership by 2030. The dedicated transitway program is an essential component to achieve the goal. As shown in Figure 1.1, Hiawatha light rail transit (LRT), I-394 HOT lane, and Northstar commuter rail are in full operation; several transitway lines are either under construction or in the planning stage of preliminary engineering.

Transitway programs represent substantial transportation investments from federal, state, and local governments. For example, Central Corridor LRT, which connects downtown Minneapolis and downtown St. Paul via University Avenue and is expected to open in 2014, costs $957 million. The public and planners are interested in ridership benefits that transitways can bring about and the strategies that can help achieve modal shift from automobile to transit. Further, the deployment of transitways offers new transit options and change relative accessibility of different areas in the regional transit network. Residential sorting associated with the deployment may enable individuals who prefer transitways to relocate to transitway neighborhoods to better match their preferences, and allow transportation-disadvantaged people to reside close to transit network. This may in turn affect transit use of station area residents. However, few studies have explored the induced transportation effects related to residential sorting. Moreover, transit-oriented development (TOD) has also been advocated to improve pedestrian access to transitway stations. Because transit users are used to pedestrian environment, TOD may promote other types of active travel, which is not related to access to stations. In other words, transitway and associated TOD may have a carryover effect on active travel. However, previous studies have yet to confirm the assumption and we are unclear which elements of the built environment around transitway stations are associated with non-motorized transportation.

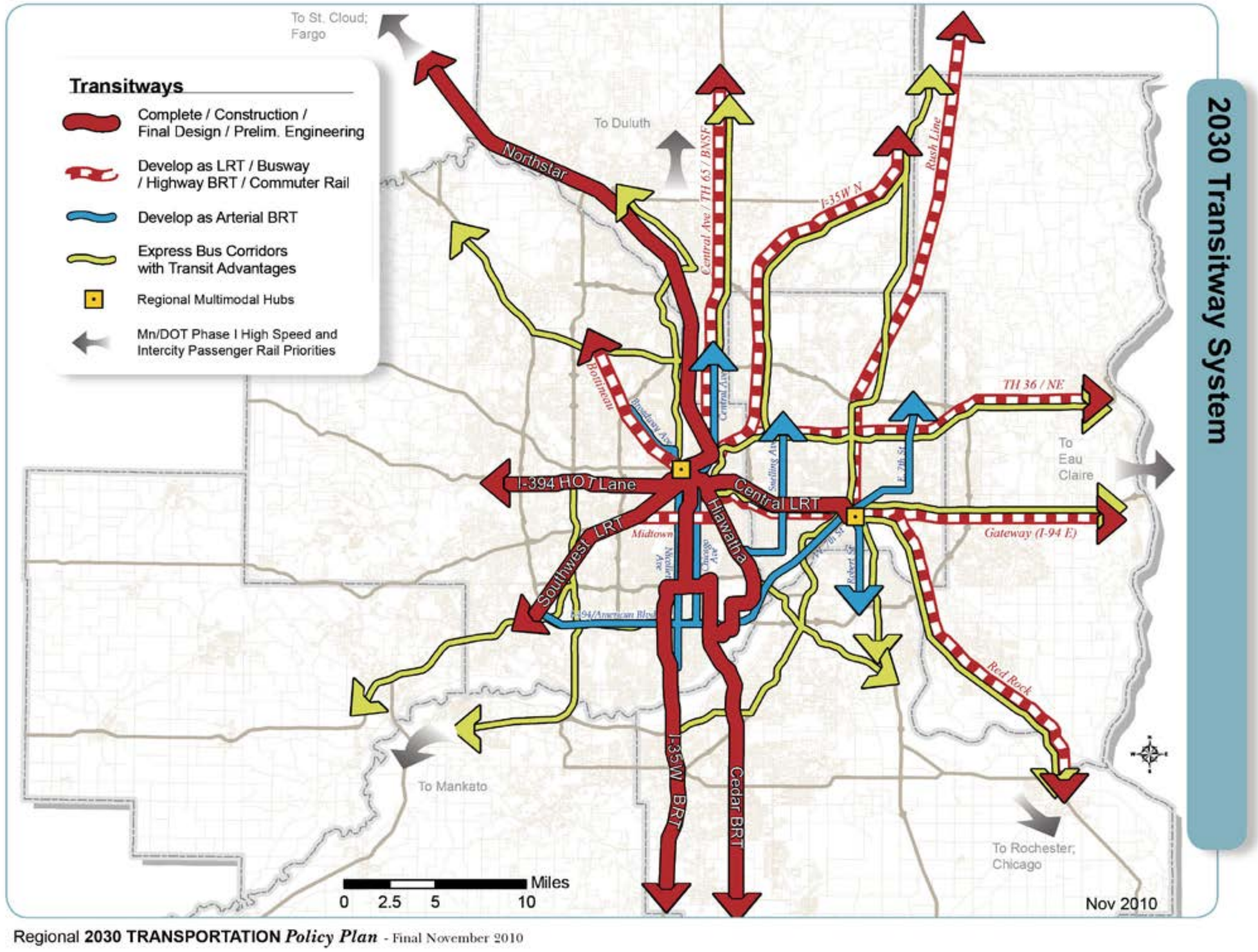

Photo Credit: Metropolitan Council. 2010. Regional 2030 Transportation Policy Plan. Available from http://www.metrocouncil.org/planning/transportation/tpp/2010/index.htm

Figure 1.1: Transitway System in the Twin Cities

Using the 2011 data collected from five corridors in the Twin Cities, this project aims to investigate reasons of living in the Hiawatha LRT corridor and associated transit use, the relationships between Hiawatha LRT and transit use, and the connections among Hiawatha LRT, the built environment and pedestrian travel within the neighborhoods. The report is organized as follows: Chapter 2 describes research design, survey administration, and the variables used in this study; Chapter 3 explores reasons of living in the Hiawatha corridor and associated transit use; Chapter 4 investigates the impact of Hiawatha LRT on transit use; Chapter 5 examines the effects of Hiawatha LRT and its built environment on pedestrian travel, which is beyond walking access to LRT stations; the final chapter concludes this study.

2. METHODOLOGY

This chapter provides an overview of the methodology used in this study. The first section describes the study design and selection of study and control corridors. Next, we discuss the survey that was administered to transitway and control residents to measure their travel behavior, travel attitudes, residential preferences, and demographics. Finally, we document the geospatial techniques used to control for built environment influences on travel behavior.

2.1 Research Design

This study employs a matched-pair cross sectional design to compare travel behavior of residents in a transitway corridor to travel behavior of those in corridors without nearby transitways. Although longitudinal studies can robustly identify the influences of land use and transportation interventions on travel behavior, they are often time-consuming and cost-inhibitive (Mokhtarian and Cao 2008). The matched-pair method allows us to compare the Hiawatha LRT corridor to corridors that are similar in terms of demographics, land use, and transit service, but lack a major transitway facility. Well-matched corridors are able to isolate the "treatment" effect of transitways on travel behavior while holding other confounding factors constant.

The target corridor in this study is Hiawatha Avenue, where the LRT is located. The Hiawatha LRT was completed in 2004. The 12-mile line has 19 stations and runs north to south between downtown Minneapolis and the Mall of America in Bloomington, Minnesota, through the Minneapolis-Saint Paul International Airport (MSP). In 2010, its ridership reached 10.5 million, which exceeded the 2020 ridership forecast by about 30% (Metropolitan_Council 2011). There are five stations located in the northernmost downtown Minneapolis area, and six stations located at the southernmost part of the line, starting at the MSP and ending at the Mall of America (Figure 2.1). The station areas at either end of the line are dominated by commercial developments or institutional land uses while the station areas in the middle of the line are dominated by industrial land uses and residential properties. The portion of the Hiawatha corridor used in this study consists of the middle section of the line, in particular, the area within ½ mile of the Hiawatha LRT from Lake Street to 50th Street. This segment is a traditional urban residential area in South Minneapolis.

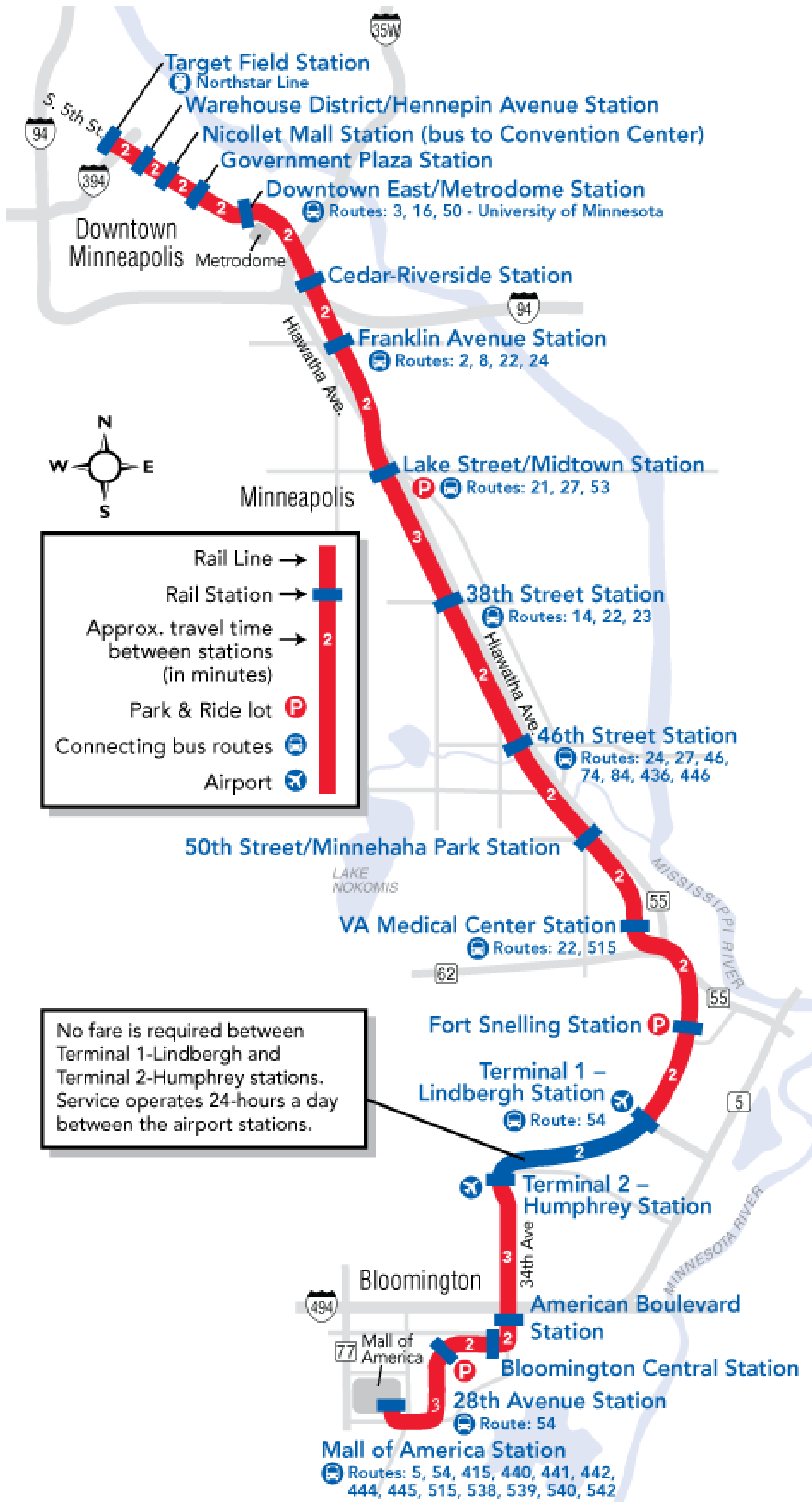

Photo Credit: Metro Transit. Maps and Schedules for Hiawatha Line (Route 55). Available from http://metrotransit.org/hiawatha-line-route-55.aspx

Figure 2.1: Hiawatha LRT

We chose two sets of control corridors to compare to Hiawatha. First, we attempted to find urban corridors that resemble the Hiawatha corridor in terms of location context, built environment elements, transit access, and demographics. With the help of local planners, we chose the areas along Nicollet Avenue and Bloomington Avenue in South Minneapolis as our urban control corridors. The two corridors are parallel to the Hiawatha line. Then we selected Coon Rapids and Burnsville as our suburban control corridors. Coon Rapids is about 12 miles north of downtown Minneapolis and Burnsville is 17 miles south of the downtown. The suburban corridors have demographics similar to the Hiawatha corridor but were mainly developed in the 1970s. The suburban corridors have a limited access to transit and their street networks are mainly curvilinear (Figure 2.2 and Figure 2.3).

2.2 Survey Data

The data came from a self-administered ten-page survey mailed in May 2011 to households in the five corridors in the Twin Cities. For each corridor, we purchased two databases of residents from AccuData Integrated Marketing, a commercial data provider (http://www.accudata.com): a database of “movers” and a database of “nonmovers.” The “movers” included all current residents who had moved to the corridor after the opening of the Hiawatha LRT or after 2004 (if they do not live along the Hiawatha corridor). From this database, we drew a random sample of about 1,000 residents from the Hiawatha corridor and about 500 residents from each of Nicollet, Bloomington, Coon Rapids, and Burnsville corridors. The database of “nonmovers” consisted of a random sample of about 1,000 residents from the Hiawatha corridor and about 500 residents from each of the four corridors, who were not included in the “movers” list for each corridor. Separating our sample into movers and nonmovers provided one way control for the effects of residential self-selection on travel behavior.

The survey was pretested by students and staff members of our School and neighbors and friends of the investigators. Survey content was revised based on the feedback from pre-testers. The survey and two reminder postcards (1 and 2 weeks later) were mailed in May 2011. Ten $50 gift cards were provided as the incentive for the survey. The original database consisted of 6,017 addresses but only 5,884 were valid. The number of responses totaled 1,303, equivalent to a 22.2% response rate based on the valid addresses only. This is considered quite good for a survey of this length, since the response rate for a survey administered to the general population is typically 10-40% (Sommer and Sommer 1997). Table 2.1 compares sample characteristics with the 2010 Census. Overall, home owners are overrepresented in the sample although the percentages of owners across different corridors are similar. Respondents tend to live in a smaller household than the population and households with children are underrepresented. These are not surprising because 54.5% of the sample is non-movers who have been living in their neighborhoods for more than seven years. On average, non-movers have a much smaller household and fewer children than movers, and almost all non-movers own their houses. In addition, these are typical results for voluntary self-administered surveys.

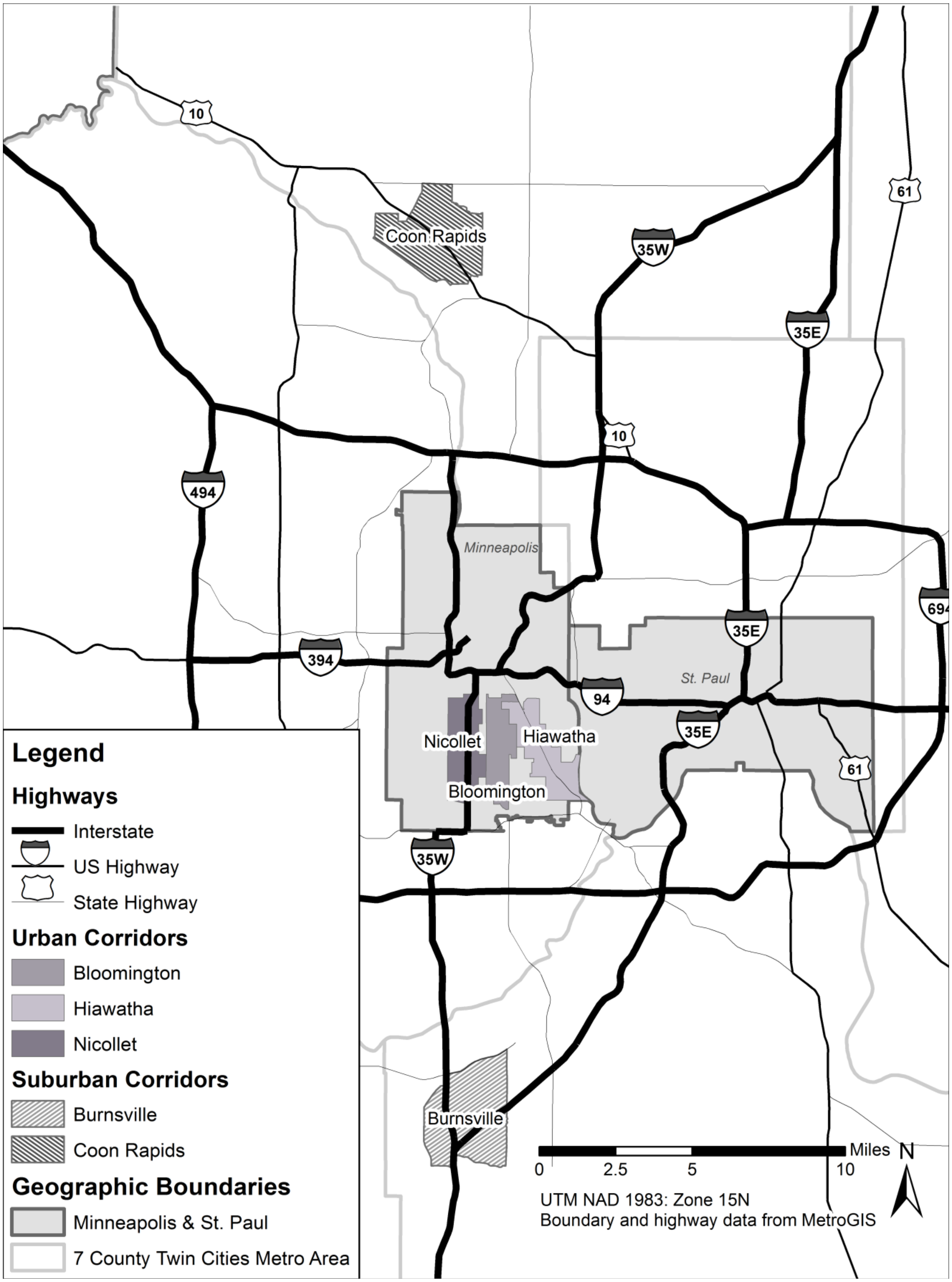

Figure 2.2: Hiawatha Corridor and Control Corridors

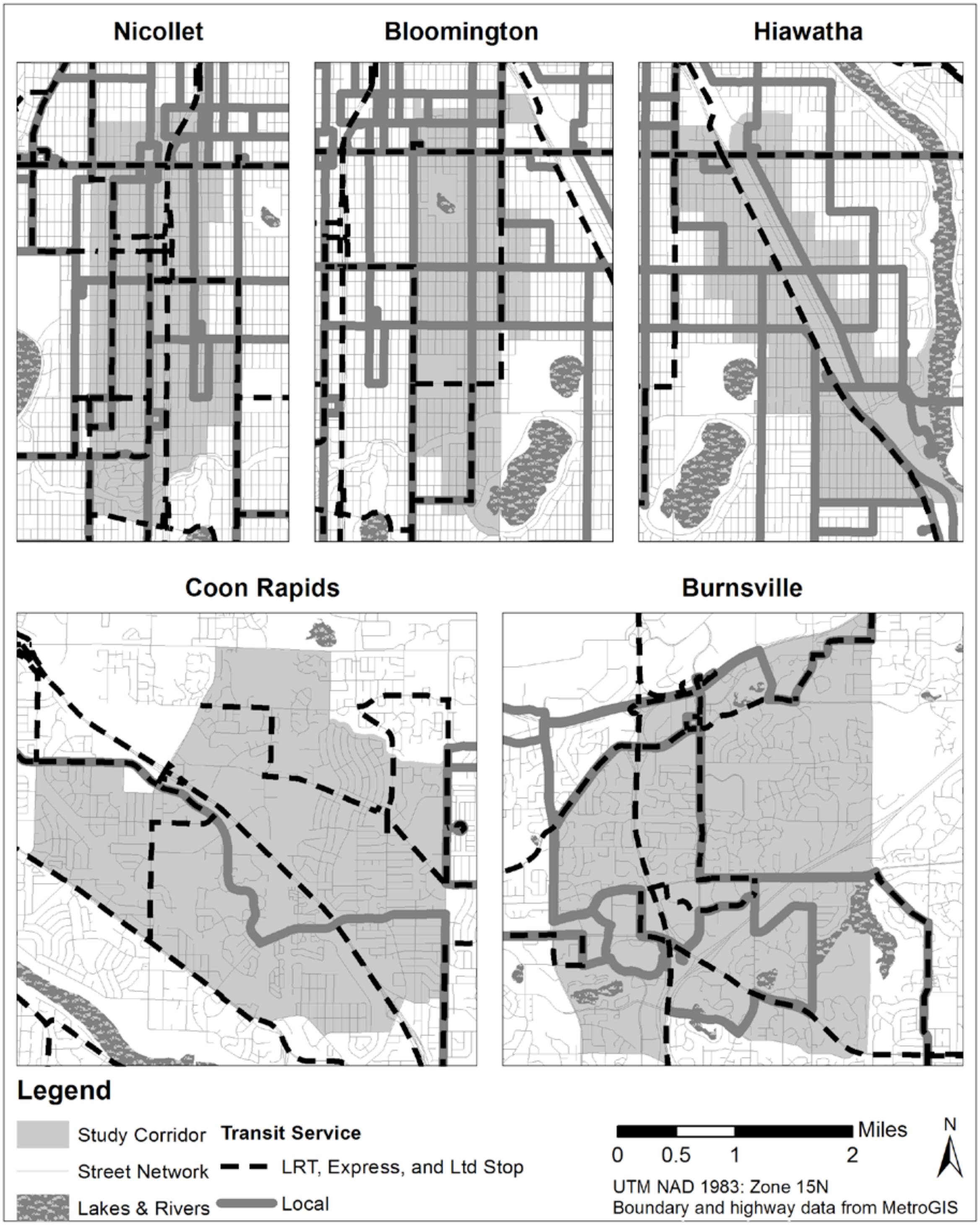

Figure 2.3: Map of Study Corridors

In the survey we asked respondents about four categories of questions, including (1) residence, neighborhood, and satisfaction, (2) daily travel, (3) travel preferences, and (4) household demographics. In the remainder of this section we briefly introduce the structure of the survey and a detailed description of variables can be found in the analysis chapters. In the first section of the survey, we asked respondents to rate how important each item on a list of 30 house and neighborhood attributes was in their residential choice, including items about land use and transportation system, safety, social environment etc. We also asked their perception on how accurately the attributes describe their current (and for movers, previous) neighborhood, and their overall satisfaction with neighborhood, daily travel, and life.

Table 2.1: Sample Characteristics vs. 2010 Census

	Hiawatha		**Nicollet**		**Bloomington**		**Coon Rapids**		**Burnsville**	
	Census	**Sample**	**Census**	**Sample**	**Census**	**Sample**	**Census**	**Sample**	**Census**	**Sample**
Number of people	24,166	508	36,808	197	27,055	241	24,866	175	27,975	182
Percent of female	50%	52%	49%	49%	50%	51%	51%	49%	52%	49%
Mean household size	2.27	2.15	2.50	2.21	2.65	2.26	2.53	2.42	2.31	2.24
Percent with kids	26%	23%	43%	22%	35%	24%	32%	29%	35%	22%
Percent owner occupied	68%	83%	49%	82%	62%	84%	77%	86%	58%	84%

The daily travel section asked respondents about their commute trip: how long it is, how much time it takes to travel, and what modes they use in a typical week. This section also asked about frequency and mode choice for non-work travel to seven categories: a religious/civic building, a service provider, a store or place to shop, a restaurant or coffee place, a place for entertainment/recreation, a place to exercise, and picking up and dropping off passengers. We also asked respondents to characterize their overall travel behavior in (1) the number of miles they drive in a typical week, (2) how often they walk for recreational or utilitarian purposes, (3) how often they ride a bike, and for movers, (4) relative changes in their use of driving, walking, biking, and transit modes before and after moving.

The third section used a set of 21 statements to elicit respondents' underlying attitudes about different modes of travel, including preferences for walking, driving, biking, transit, and overall travel; concern for safety of other modes relative to driving; and driving and car ownership as a status symbol. The last section of the survey included a series of household and demographic questions relevant to the respondent's gender, age, employment and educational status, limitations that constrain mode choice, vehicle ownership, household size, income, and so on.

2.3 Geospatial Data

Following the survey, we constructed a set of objective built environment measures around each respondent's home address using ArcGIS. Some variables measured the distance from each respondent's home address to the nearest feature, such as transit stops or consumer-oriented businesses. We also measured characteristics around each respondent's home, using a ¼-mile, ½-mile, and 1-mile network distance buffer. These characteristics included measures of density, land use mix, presence of local businesses, and transportation infrastructure. Where appropriate, we selected variables from this built environment set to include when modeling trip behavior among survey respondents. The variables and their respective spatial units and measurement techniques are described below.

2.3.1 Measures of Density

We measured population density and occupied housing unit density per acre using 2010 US Census data in the ¼-mile, ½-mile, and 1-mile residential buffers.

2.3.2 Measures of Land Use and Housing

We used a spatial dataset of land use within the Twin Cities Metro Area (Metropolitan Council land use dataset: http://datafinder.org/metadata/GeneralizedLandUse2010.html) to compute:

- Area within each buffer and percent of land within each buffer for residential, commercial, office, institutional, industrial, and open space land use types.
- Land use entropy, a measure of the mix of different land use types within an area, using the following equation:

$$S(X) = -\frac{\left[\sum_{i=1}^{n} p(x_i)\ln\big(p(x_i)\big)\right]}{Ln(n)} \; for \; X = \begin{bmatrix} Residential \\ Commercial \\ Office \\ Institutional \\ Industrial \end{bmatrix}$$

where $p(x_i)$ is the proportion of the x_i type of land uses. This index ranges from 0 to 1, with 0 being homogenous use and 1 indicating equal presence of different uses.

- Housing mix entropy to measure how diverse the housing stock is within the buffer around each respondent's house using the following equation:

$$H(Y) = -\frac{\left[\sum_{i=1}^{m} p(y_i)\ln\big(p(y_i)\big)\right]}{Ln(m)} \; for \; Y = \begin{bmatrix} Single\ Family \\ Duplex/Townhome \\ Condo/Apartment \\ MixedUse\ Residential \end{bmatrix}$$

where $p(y_i)$ is the proportion of the y_i type of housing options.

2.3.3 Measures of Local Business Activity

We collected a list of addresses of local businesses near our survey respondents from a commercial database available on the U of M campus (ReferenceUSA). We geocoded these businesses and measured proximity and access to businesses for all respondents. We selected businesses by NAICS code that fit into the six categories presented in the travel section of the survey:

- A religious or civic building (ex., library)
- A service provider (ex., bank, barber)
- A store or place to shop
- A restaurant or coffee place
- A place for entertainment/recreation

- A place to exercise (gym)

For each business type, we constructed the following measures:

- Network distance to the nearest [business], in miles
- [Business] intensity: a count of the number of [business] within a buffer
- [Business] density: the number of [business] per acre

From these measures by business type, we calculated the following aggregate business measures:

- Distance to the nearest business of any type, in miles
- Business mix entropy, a measure of how varied the types of businesses are within each buffer, using the following equation:

$$B(Z) = -\frac{\left[\sum_{j=1}^{n} p(z_j)\ln\left(p(z_j)\right)\right]}{\mathrm{Ln(n)}}\ for\ Z = \begin{bmatrix} A\ religious\ or\ civic\ building\ (ex., library) \\ A\ service\ provider\ (ex., bank, barber) \\ A\ store\ or\ place\ to\ shop \\ A\ restaurant\ or\ coffee\ place \\ A\ place\ for\ entertainment/recreation \\ A\ place\ to\ exercise\ (gym) \end{bmatrix}$$

where $p(z_j)$ is the proportion of the z_j type of business establishments.

2.3.4 Measures of Transportation Infrastructure

These measures use datasets of transit routes (Metro Transit routes dataset: datafinder.org/metadata/TransitRoutes.html) and stops (Metro Transit stops dataset: http://datafinder.org/metadata/TransitStops.html) within the Twin Cities to characterize opportunities for residents to connect to the transit network within a ¼-, ½-, or 1-mile buffer around their home. We measured proximity to transit in several ways:

- Network distance to the nearest transit stop or station, in miles
- Transit stop intensity: a count of the number of stops within a buffer
- Transit stop density: the number of stops per acre
- Transit route intensity: a count of the number of routes passing through a buffer that actually stop within the buffer, excluding express routes that may pass nearby but do not stop
- Transit route density: the number of routes that stop in the buffer per acre

Street connectivity measures characterize how interconnected the grid of local streets is around the respondent's home. Higher levels of connectivity suggest greater opportunity to connect to the broader transportation network. We used a dataset of the road network (Addressable street centerlines dataset: http://www.metrogis.org/data/datasets/street_centerlines/index.shtml) to measure street network connectivity in the following ways:

- 4-way intersection intensity: a count of the 4-way (or higher) intersections in a buffer.
- 4-way intersection density: the number of 4-way intersections per acre

- Cul-de-sac intensity: a count of the number of cul-de-sacs or dead-end streets in abuffer
- Cul-de-sac intensity: the number of cul-de-sacs or dead-end streets per acre

Bicycle facilities were measured using a spatial dataset from the Metropolitan Council (Metropolitan Council bikeways dataset: http://datafinder.org/metadata/Bikeways.html). We measured access to bike lanes and trail facilities separately and combined, as follows:

- Lane intensity: miles of bike lane within a buffer
- Path intensity: lane-miles of combined use path within a buffer
- Facility intensity: the sum of lane-miles of path and miles of bike lane within a buffer
- Lane density: miles of bike lanes per acre
- Path density: miles of path per acre
- Facility density: the sum of lane-miles of path and miles of bike lane per acre

3. RESIDENTIAL PREFERENCES OF HIAWATHA RESIDENTS

Not all residents move to rail transit corridors for the quality of transit service and access to transit. When looking for a place to live, individuals always face various choices including price, transportation systems, accessibility, safety, quality of the living unit and neighborhood, and so on (Rossi 1980; Hunt, McMillan et al. 1994). Residents who prefer transit may show a different pattern of transit use than those moving to the corridor for other reasons. However, there are a limited number of studies on the motivations for living close to rail transit and associated transit use.

This chapter will answer the following questions: (1) Who relocates to the LRT corridor? (2) What factors do the residents prioritize when they move to the corridor? (3) How do the residents and their preferences differ from those moving to comparable control corridors? (4) Who is likely to have a strong preference for transit? (5) Is transit use a result of residential self-selection? As discussed in details later, it is unique in three aspects. First, compared to previous studies on residents around rail stations, it measures residential preferences comprehensively: the 30 items capture various dimensions of residence and neighborhood, especially the characteristics pertinent to transportation systems and access to different land uses. Second, it measures the importance of the characteristics in residential choice in two ways, which allows us to investigate how the results differ due to research design. Finally, it evaluates residential preferences of residents in urban corridors with and without the LRT, which enables us to identify the potential advantages of the LRT over buses in attracting transit patrons and facilitate transit use.

3.1 Background

Residential preference has become a key component in the debate over the relationship between the built environment and travel behavior (TRB and IOM 2005). It is a major source of residential self-selection (RSS): people choose their residential locations based on their mobility needs or desire (Cao, Mokhtarian et al. 2009). For example, individuals who prefer transit may selectively live in a transit-oriented neighborhood, and then use transit more. In this case, the preference for transit is antecedent to both residential and travel choices and transit-oriented neighborhood is a viable option of residential environments that facilitates transit behavior. A number of recent studies have measured residential preferences and incorporated them in the models for land use and travel behavior (Khattak and Rodriguez 2005; Cao, Handy et al. 2006; Frank, Saelens et al. 2007; Joh, Boarnet et al. 2008). They substantiate the influence of residential preferences on travel behavior (Cao, Mokhtarian et al. 2009). Other studies treat residential preferences as unobserved factors and employ joint models to control for their influences (Bhat and Guo 2007; Bhat and Eluru 2009). Although most studies find that the built environment tends to have a larger impact on travel behavior than residential preferences (Cao, Xu et al. 2010), residential preferences play a very important role.

What factors drive individuals' decision for residential location choice? Traditional theory regards residential choice a tradeoff among housing costs, commuting costs, and costs of other goods and services (Alonso 1964). This highlights the importance of job accessibility. Further, the preferences may differ by different segments of people. For example, because affluent households are more likely to afford extra commuting costs than low-income households, they often outbid the low-income for suburban housing (Giuliano 2004). Because of extensive highway network, job accessibility is relatively high at anywhere in modern polycentric metropolitan areas. The importance of job accessibility decreases. Moreover, the proliferation of multiple-worker households, cheap transportation costs, and the emerging importance of other factors such as amenities and school quality contribute to its decline (Giuliano 1991).

How is the relative importance of different factors in residential choice evaluated? Some studies apply stated-choice experiments (Bina, Warburg et al. 2006; Levine and Frank 2007; Olaru, Smith et al. 2011). In the studies, respondents are asked to choose among two or more hypothetical options which have different values on several neighborhood attributes (Train 2003). Stated-choice experiments can generally be effective to identify the preferences for non-existing (or not widely available) products or services (Hensher 1994). However, they also have many limitations. First, stated-choice methods do not measure actual behavior – "what people say they will do is often not the same as what they actually do" (Train 2003)(p. 157). Second, to reduce the burden of respondents, researchers can test only a limited number of attributes while holding others such as price constant. Although these attributes are of interest to researchers, they may not play a dominant role among various factors influencing residential choice. Further, those other attributes may vary with examined attributes simultaneously. For example, new urbanism features are likely to increase housing values (Song and Knaap 2003). This design makes hypothetical situations even more unrealistic. There is also a concern that "survey researchers' practice of bundling housing characteristics into stereotypical descriptions obscures consumer preference or distaste for specific residential amenities" (Myers and Gearin 2001)(p. 639). In addition, this method suffers from various sources of bias such as affirmation bias – saying what they think the researcher wants to hear (Train 2003).

Some studies ask respondents to indicate how important various features regarding residence and neighborhood are during their home search process. (Bina, Warburg et al. 2006) investigate transportation and location choices of apartment dwellers, using the 2005 data collected from Austin, TX. They conclude that price is the most important among the attributes examined; crime rate and neighborhood attractiveness are very important; but accessibility to shopping and services is much less important. (Filion, Bunting et al. 1999) find that place-related attributes (such as safety and attractiveness) of neighborhoods are more important than accessibility to transportation systems and land uses, using the 1998 data from Kitchener-Waterloo, Canada. After examining the 2003 data in Northern California, (Cao 2008) also point to the secondary role of transportation opportunities in the choice of residential neighborhoods. However, there are limited applications of this approach to neighborhoods around rail stations.

(Lund 2006) ask respondents (who moved to TOD in the last five years) to indicate the top three reasons (among eight) to relocate to transit-oriented developments (TODs) in California. Overall, she finds that type or quality of housing, cost of housing, and quality of neighborhood are top three among all residents although the ranking varies for different rail systems. An exception is residents in San Francisco Bay Area who value access to transit more than quality of neighborhood. As she points out, her study has several limitations: no control groups (either cross-sectional or longitudinal) are present, the sample is from a few buildings (as opposed to random sampling), and respondents are biased toward English speaking population.

This chapter follows the structure of (Lund 2006). However, it focuses on a recently completed LRT corridor where residential sorting is dynamically happening whereas (Lund 2006) explores mature neighborhoods around rail transits which opened decades ago.

3.2 Results and Discussion

3.2.1 Sample Characteristics

Table 3.1 compares the characteristics of some respondents in the sample. Again, non-movers are residents who have lived in their corridors before the opening of the LRT. Movers are those who relocated to their neighborhoods after 2004. In this sample, Hiawatha movers have a higher level of education and are younger than Hiawatha non-movers. The age pattern is consistent with (Lund 2006). Compared to non-movers, Hiawatha movers are more likely to be workers and renters. There are no significant differences in household size, income, share of women, and car ownership per driver between movers and non-movers in the Hiawatha corridor. From now on, all discussions in this section are based on the sub-sample of movers in different corridors.

Table 3.1 shows no differences in demographics between residents in the Hiawatha corridor and those in the urban control corridors (called urban residents for simplicity). Therefore, the LRT does not attract different residents than bus corridors. This is distinct from the findings of previous studies which use the city or locality where rail transit is located as controls (Lund 2006; Dill 2008). In contrast, residents in the suburban control corridors (called suburban residents for simplicity) tend to live in a larger household and are older than Hiawatha residents whereas the latter is more likely to be well-educated, employed, and affluent than the former.

3.2.2 Residential Preferences

During residential search process, preferences for accessibility and transportation systems are not the only influential factors. In the survey, respondents were asked to indicate how important each of the 30 characteristics was when they were looking for a place to live, on a four-point scale ranging from “not at all important” to “extremely important.” Among the 30, ten are pertinent to transportation systems and access to different land uses, as shown in the third and fourth blocks of characteristics in Table 3.2. In addition, the characteristics cover other dimensions such as social environment, safety, and the quality of neighborhoods. The importance for neighborhood and residence characteristics rated by respondents reflects fundamental differences in their residential preferences.

Table 3.1: Characteristics of Movers and Non-Movers

	Hiawatha Movers	Hiawatha Non-movers	Urban Movers	Suburban Movers
Household size	2.22	2.06	2.28	**2.52**
Income	5.65	5.41	5.73	**5.16**
Education	4.25	**3.86**	4.40	**3.77**
Age	40.6	**57.5**	41.0	**45.8**
Share of workers	0.84	**0.72**	0.89	**0.71**
Share of renters	0.27	**0.05**	0.28	0.31
Share of female	0.56	0.47	0.52	0.56
Number of cars per driver	0.98	1.07	0.95	1.03
N	267	241	189	137

The bolded entry indicates it is significantly different from the same attribute of Hiawatha movers at the 0.05 level.

Among the 30 attributes, 21 do not show significant differences between residents in the Hiawatha and urban control corridors. One characteristic is marginally significant: Hiawatha residents prefer "attractive appearance of neighborhood" more than urban residents. Further, the differences in eight attributes are significant. In particular, Hiawatha residents are more likely to value "easy access to a regional shopping mall", "low crime rate within neighborhood", and "safe neighborhood for walking" than urban residents, whereas the latter tends to prefer "lots of interaction among neighbors", "lots of people out and about within the neighborhood", and "diverse neighbors in terms of ethnicity, race, and age" more than the former. More importantly, Hiawatha residents favor "good public transit service (bus or rail)" and "easy access to transit stop/station" more strongly than urban residents.

Fifteen characteristics are significantly different between Hiawatha and suburban residents. It is worth noting that eight are related to transportation systems and access to land uses. In contrast, only three characteristics are significantly different between Hiawatha and urban residents, and among the three, two are pertinent to transit. This highlights the uniqueness of the LRT. In general, Hiawatha residents are more likely to prefer alternative transportation facilities and access to activities than suburban residents, except "easy access to a regional shopping mall". Residents appear to consciously choose to live in the neighborhoods that match their preferences for land use and transportation system; that is, people self-select.

Although Table 3.2 shows residents' differences in residential preferences, it cannot illustrate the characteristics that residents value the most. In this study, we adopt two ways to evaluate the most important factors. As shown in the middle block in Table 3.3, we first rank the characteristics based on the percentage of respondents who rated them "extremely important". In the Hiawatha corridor, the top three characteristics are "affordable living units", "safe neighborhood for waking", and "parks and open spaces nearby" and the two transit-related attributes rank the fourth and fifth. Overall, the top ten characteristics are pertinent to living unit itself, safety, and alternative transportation systems. Urban residents also value the ten characteristics the most although the order of ranking somewhat varies between Hiawatha and urban residents. To the contrary, much fewer suburban residents value the four characteristics related to alternative transportation systems than Hiawatha and urban residents.

Although people may think many characteristics are important, it is virtually impossible for them to find a place that meets all of their expectations (Schwanen and Mokhtarian 2004; Cao 2008). Therefore, they have to prioritize their preferences for some characteristics and compromise their preferences for others. Similar to (Lund 2006), respondents were also asked to check three characteristics they considered the most important in their residential choices. Note that about a quarter of residents did not answer this question.

The ranking of the characteristics is presented in the last block of Table 3.3. First, except "affordable housing unit" for all residents and "low crime rate within neighborhood" for suburban residents, none of the characteristics were chosen by more than one third of respondents. This reflects individuals' diverse preferences. Second, the order of ranking is quite different for some characteristics. For example, for suburban residents, good transit service ranks the 6th whereas it ranks the 24th in the "extremely important" ranking discussed above; "close to where I work" ranks the 3rd for suburban residents and the sixth for urban residents whereas it ranks the 11th and 12th for all three groups of residents in the "extremely important" ranking. The differences arise from different designs. Checking the top three characteristics is a constrained choice in which respondents need to evaluate the relative importance of different factors. Rating characteristics one by one is unconstrained because of the independence of rating different attributes. Therefore, the former is more reliable than the latter. For Hiawatha residents, the top four characteristics are the same as the top four in the "extremely important" ranking. Urban residents share the top four characteristics with Hiawatha residents. Overall, affordability and safety are prioritized by the residents of all corridors. This finding is consistent with previous research (Filion, Bunting et al. 1999; Bina, Warburg et al. 2006; Cao 2008). Good transit service and job accessibility are also very important. About 20-25% of residents favor the two characteristics.

Table 3.2: Differences in Residential Preferences among Corridors

Residential Preferences	Hiawatha	Urban	p-value	Suburban	p-value
Affordable living unit	3.71	3.66	0.381	3.83	**0.012**
High quality living unit	3.39	3.42	0.617	3.36	0.692
Living unit on cul-de-sac rather than through street	1.27	1.26	0.807	1.89	**0.000**
Good investment potential	2.77	2.76	0.953	2.82	0.633
High quality k-12 schools	2.06	2.12	0.585	2.31	0.058
Attractive appearance of neighborhood	3.31	3.19	0.056	3.24	0.373
Variety in housing styles	2.53	2.46	0.496	2.35	0.124
High level of upkeep in neighborhood	3.20	3.25	0.464	3.1	0.266
Large back yards	2.25	2.20	0.620	2.48	**0.042**
Lots of off-street parking (garages or driveways)	2.92	2.78	0.130	3.06	0.185
Sidewalks throughout the neighborhood	3.24	3.24	0.972	2.58	**0.000**
Good bicycle routes beyond the neighborhood	2.88	2.98	0.385	2.17	**0.000**
Good public transit service (bus or rail)	3.32	3.03	**0.004**	2.15	**0.000**
Easy access to transit stop/station	3.27	2.87	**0.000**	2.18	**0.000**
Parks and open spaces nearby	3.37	3.39	0.774	3.11	**0.008**
Shopping areas within walking distance	2.79	2.70	0.304	2.28	**0.000**
Easy access to a regional shopping mall	2.15	1.89	**0.006**	2.74	**0.000**
Easy access to downtown	2.98	2.92	0.561	2.27	**0.000**
Religious or civic buildings (ex., library) nearby	2.45	2.31	0.169	2.42	0.784
Close to where I work	3.01	3.02	0.930	2.84	0.135
Low crime rate within neighborhood	3.37	3.22	**0.043**	3.39	0.796
Low level of car traffic on neighborhood streets	2.80	2.70	0.265	3.02	**0.022**
Quiet neighborhood	3.04	2.91	0.101	3.19	0.088
Good street lighting	2.93	2.85	0.380	2.91	0.876
Safe neighborhood for walking	3.57	3.43	**0.049**	3.37	**0.022**
Safe neighborhood for kids to play outdoors	2.76	2.82	0.580	2.94	0.173
Lots of interaction among neighbors	2.49	2.70	**0.031**	2.32	0.120
Lots of people out and about within the neighborhood	2.68	2.87	**0.041**	2.35	**0.001**
Diverse neighbors in terms of ethnicity, race, and age	2.48	2.68	**0.048**	2.13	**0.002**
Economic level of neighborhoods similar to my level	2.36	2.28	0.398	2.33	0.794

The bolded entry indicates that it is significantly different from the same attribute of Hiawatha residents at the 0.05 level, and the red entry is significant at the 0.1 level.

Table 3.3: Rankings of Residential Preferences

Residential Preferences	Ranking of Extremely Important						Ranking of Top Three Characteristics					
	Hiawatha	Rank	Urban	Rank	Suburban	Rank	Hiawatha	Rank	Urban	Rank	Suburban	Rank
Affordable living unit	75%	1	75%	1	84%	1	42%	1	47%	1	62%	1
Safe neighborhood for walking	66%	2	58%	3	57%	3	26%	4	23%	4	21%	7
Parks and open spaces nearby	58%	3	58%	2	43%	8	27%	2	27%	2	10%	13
Good public transit service (bus or rail)	56%	4	47%	6	16%	24	26%	3	26%	3	21%	6
Easy access to transit stop/station	55%	5	40%	11	19%	22	13%	10	4%	19	4%	15
Low crime rate within neighborhood	51%	6	41%	10	59%	2	24%	5	20%	5	38%	2
Sidewalks throughout the neighborhood	51%	7	51%	5	23%	18	4%	19	6%	16	3%	17
High quality living unit	49%	8	53%	4	50%	4	16%	7	19%	7	21%	5
Safe neighborhood for kids to play outdoors	42%	9	43%	8	49%	5	12%	11	13%	10	25%	4
Good bicycle routes beyond the neighborhood	42%	10	44%	7	16%	25	15%	8	14%	9	3%	18
Attractive appearance of neighborhood	39%	11	37%	13	45%	6	5%	15	10%	12	7%	14
Close to where I work	39%	12	39%	12	37%	11	23%	6	19%	6	25%	3
High level of upkeep in neighborhood	37%	13	42%	9	39%	10	4%	18	13%	11	10%	10
Easy access to downtown	36%	14	36%	14	18%	23	5%	16	7%	14	1%	24
Good investment potential	33%	15	32%	15	35%	13	13%	9	16%	8	14%	8
Good street lighting	31%	16	30%	16	33%	14	3%	24	1%	26	1%	25
Quiet neighborhood	31%	17	25%	20	41%	9	7%	14	1%	25	3%	22

	Ranking of Extremely Important						Ranking of Top Three Characteristics					
Residential Preferences	**Hiawatha**	**Rank**	**Urban**	**Rank**	**Suburban**	**Rank**	**Hiawatha**	**Rank**	**Urban**	**Rank**	**Suburban**	**Rank**
Lots of off-street parking (garages or driveways)	30%	18	29%	18	43%	7	8%	12	6%	15	10%	12
Shopping areas within walking distance	26%	19	23%	22	20%	20	5%	17	4%	20	3%	19
Low level of car traffic on neighborhood streets	23%	20	20%	24	37%	12	0%	30	0%	30	0%	27
Variety in housing styles	22%	21	19%	25	21%	19	1%	26	1%	23	3%	16
Lots of people out and about within the neighborhood	21%	22	30%	17	12%	28	1%	25	4%	21	0%	29
Religious or civic buildings (ex., library) nearby	20%	23	12%	28	20%	21	3%	23	1%	24	3%	21
High quality k-12 schools	18%	24	21%	23	26%	16	4%	20	4%	18	14%	9
Diverse neighbors in terms of ethnicity, race, and age	18%	25	28%	19	10%	30	7%	13	9%	13	3%	23
Lots of interaction among neighbors	17%	26	23%	21	11%	29	3%	21	6%	17	0%	28
Easy access to a regional shopping mall	15%	27	9%	29	29%	15	1%	27	0%	28	3%	20
Economic level of neighborhoods similar to my level	13%	28	12%	27	13%	26	0%	28	1%	27	0%	30
Large back yards	10%	29	12%	26	24%	17	3%	22	1%	22	10%	11
Living unit on cul-de-sac rather than through street	3%	30	2%	30	13%	27	0%	29	0%	29	0%	26

3.2.3 Preferences for Transit

Hiawatha residents are more likely to prefer access to transit and good transit service than urban residents, who in turn favor them more than suburban residents. Residential preferences are measured on a four-point ordinal scale. Ordered logit models are developed to explore the covariates of preferences for the transit-related characteristics (Table 3.4). Because residents living in the same corridor may share some attributes, corridor dummy variables are included in the model to capture the fixed effect of spatial dependence.

Table 3.4: Ordered Logit Model for Transit Preferences

	Easy Access		**Good Service**	
	Coefficient	**p-value**	**Coefficient**	**p-value**
Threshold_1	-1.156	0.137	-2.097	0.017
Threshold_2	-0.125	0..872	-1.204	0.169
Threshold_3	-1.369	0.080	-0.493	0.574
Demographics				
Limitations on walking	-1.139	0.050	-1.117	0.052
Driver's license	-1.003	0.102	-1.701	0.019
Income	-0.115	0.004	-0.118	0.004
Number of cars per driver	-0.383	0.031	-0.438	0.015
Travel attitudes				
I like taking transit.	0.239	0.023	0.310	0.004
Public transit can sometimes be easier for me than driving.	0.269	0.001	0.210	0.014
I prefer to take transit rather than drive whenever possible.	0.383	0.000	0.435	0.000
Perceptions of previous neighborhoods				
Easy access to transit stop/station	0.254	0.001		
Good public transit service			0.162	0.046
Burnsville	-1.240	0.000	-1.438	0.000
Coon Rapids	-1.154	0.000	-1.333	0.000
Bloomington	-0.661	0.004	-0.376	0.110
Nicollet	-0.834	0.002	-0.497	0.068
Hiawatha	Reference		Reference	
N	551		552	
Veall-Zimmermann R^2	0.423		0.449	

The Veall-Zimmermann R^2 is chosen as a goodness-of-fit measure for the models because it is better than McFadden R^2 when the number of ordinal categories exceeds three (Veall and Zimmermann 1996).

Independent variables include demographic and attitudinal characteristics. We find that limitations on walking, having a driver’s license, income, and car ownership per driver are significantly and negatively associated with preferences for access to transit and good transit service. In other words, individuals with walking constraints, those without a license, low-income people, and those without cars highly value the transit characteristics. Further, to measure attitudes on riding transit, the survey asked respondents whether they agreed or disagreed with transit-related statements on a 5-point scale from "strongly disagree" (1) to "strongly agree" (5). We find that residents who positively value transit are more likely to prefer residential neighborhoods with good transit access and service. Thus, a high level of residential preferences for transit reflects both a need for transit as a mobility instrument and an intrinsic affection toward transit.

Good transit service as perceived by respondents for their previous neighborhoods (where they lived before they relocated) is a positive predictor for the preference for the same characteristic. So is easy access to transit stop/station. These substantiate that the built environment reinforces preferences for the environment and hence the connections between the built environment and residential preferences are mutual. This is consistent with (Chen and Lin 2011).

3.2.4 Transit Use

We developed an ordinal logit model for commute frequency and a linear regression model for total non-work trip frequency. In the survey, respondents were asked to indicate the number of days they used bus/rail to commute in a typical week with good weather, based on a six-point ordinal scale ranging from "Never", "Less than once per month", "1-3 times per month", "Once per week", "2-3 days per week", to "4-5 days per week". Respondents were also asked to answer the following question: "In ***a typical month with good weather***, how often do you take ***public transit*** from your home to each of the following places ***for purposes other than work/school***?" The survey lists seven non-work purposes including "A religious or civic building (ex., library)", "A service provider (ex., bank, barber)", "A store or place to shop", "A restaurant or coffee place", "A place for entertainment/recreation", "A place to exercise (ex., a gym or a park)", and "To pick up or drop off a passenger". The answer choice set includes "Never", "Less than once per month", "Once or twice per month", "About once every two weeks", "About once per week", and "Two or more times per week". They are recoded as approximately "0", "0.5", "1.5", "2.15", "4.3", and "12.9" trips per month, respectively. The total non-work trip frequency is a summation of frequencies for the seven purposes.

Independent variables include both demographics and residential preferences for good transit service and easy access to transit. Because the two transit-related preferences are highly correlated, a principle axis factor analysis is used to reduce the two dimensions to a single factor for transit preferences. Table 3.5 presents both models. As we expect, car ownership per driver and ownership of a driver's license are negatively associated with both commute and non-work trip frequencies. For non-work trips, people with limitations on driving tend to use transit more often whereas those with limitations on taking transit tend to ride transit less frequently. Income has a negative association with transit frequency and renters tend to use transit more frequently than owners. A comparison of coefficients shows that driver's license, limitations on driving and limitations on taking transit have very large coefficients. Thus, captive riders are major patrons of transit. This is consistent with user patterns of transit (Pucher and Renee 2003). For commute trips, women, the elderly, and workers are less likely to use transit frequently. Interestingly, bike ownership is also negatively related to transit use. This implies that bicycle competes with transit as a commuting mode.

Table 3.5: Models for Transit Use

	Non-work travel		Commute	
	Coefficient	**p-value**	**Coefficient**	**p-value**
Mu_1			-3.330	0.000
Mu_2			-2.639	0.000
Mu_3			-2.272	0.002
Mu_4			-2.024	0.006
Mu_5			-1.536	0.037
Constant	19.779	0.000		
Transit preference	1.950	0.000	1.210	0.000
Number of cars per driver	-1.605	0.033	-0.688	0.005
Driver's license	-13.017	0.000	-1.426	0.005
Limitations on driving	11.759	0.001		
Limitations on taking transit	-10.550	0.000		
Renter	2.100	0.027		
Income	-0.343	0.066		
Worker			-0.845	0.027
Age			-0.025	0.009
Female			-0.386	0.057
Number of bikes			-0.098	0.077
Bloomington	0.848	0.408	0.342	0.191
Burnsville	0.007	0.995	-0.381	0.378
Coon Rapids	-0.230	0.870	-0.828	0.149
Nicollet	0.582	0.613	0.464	0.109
Hiawatha	Reference		Reference	
N	558		513	
Veall-Zimmermann R^2			0.389	
Adjusted R-square	0.232			

After controlling for demographics, the transit preference factor has a positive association with both non-work and commute frequencies. Since urban residents are more likely to favor transit than suburbanites, residents who prefer transit consciously choose to live in neighborhoods conducive for transit, and they ride transit more. Thus, residential self-selection effect exists. Moreover, although demographics related to transportation-disadvantaged people are good predictors for transit preference (Table 3.4), the preference has an independent impact on transit use. (Brownstone and Golob 2009) indicate that self-selection effect can be well captured by including demographics in the model. This study shows that incorporating demographics is not sufficient to capture attitude-induced self-selection.

3.3 Summary

This chapter explores motivations for people moving into the corridor of the Hiawatha LRT and their connections with transit use. We find that residents who moved to the Hiawatha corridor after the opening of the LRT are distinct from those who moved there before its opening: the former tends to have a higher education, be younger and is more likely to be renters than the latter. The differences contribute to different patterns of transit use. Although movers in the Hiawatha corridor differ from movers in suburban corridors, residents in Hiawatha and urban control corridors are not significantly different.

In terms of residential preferences, suburban and urban residents favor different characteristics, especially those related to transportation systems and access to land uses. However, there are few differences in the preferences for accessibility and transportation systems between urban residents who are close to or far from the LRT, except for transit-related attributes and access to regional mall. Consistent with previous studies, affordability and safety are first-priority factors when people decide where to live. Alternative transportation systems are more important for urban dwellers than suburbanites. When respondents were asked to choose the top three factors (a constrained choice), good transit service and job accessibility turn out to be very important for both urban and suburban residents, right after affordability and safety. Thus, comparing unconstrained choices may obscure their role in residential choice.

The models for residential preferences for transit show that they are significantly associated with the characteristics of transportation-disadvantaged people and individuals' intrinsic affection toward transit. Further, people who prefer residential neighborhoods with good transit access and service tend to use transit more frequently. After controlling for demographics and transit preferences, the Hiawatha LRT does not have a separate impact on transit use, compared to both urban and suburban corridors. Because urban and suburban residents prefer land use and transportation attributes differently and use transit at different frequencies, this finding indicates the existence of a self-selection effect (Mokhtarian and Cao 2008). However, this does not mean that neighborhoods well served by transit have no effects on transit use; instead, these neighborhoods attract residents with certain characteristics, who tend to use transit more frequently than others. On the other hand, because there are no significant differences in transit use and demographics between urban corridors with and without LRT, the Hiawatha LRT and bus are equally attractive in facilitating self-selection.

4. LIGHT RAIL TRANSIT AND TRANSIT USE

To justify massive rail transit investments, a number of studies have explored the ridership bonus of rail transit and associated development around station areas. Previous studies tend to overstate the influence of a new rail line on transit use among station area residents, however. Rail transit often replaces a high-frequency bus route with heavy demand. The studies overwhelmingly used residents in the city/county/region instead of residents in comparable neighborhoods with well-served bus transit. Further, residential self-selection implies that rail transit may influence transit use of movers and non-movers differently and the ridership bonus of movers may not indicate a preference for rail transit over bus. In this chapter, we apply the propensity score matching approach to fill in the two gaps and evaluate the impact of the Hiawatha LRT on transit use among station area residents.

4.1 Background

In lieu of expensive and time-consuming longitudinal design, scholars often conduct matched-pair cross-sectional studies to examine the relationships between the built environment and travel behavior. For example, previous studies compare travel behavior of residents living in traditional neighborhoods and suburban neighborhoods (Handy, Cao et al. 2005; Joh, Boarnet et al. 2008; Aditjandra, Mulley et al. 2009). The validity of policy implications from the studies heavily relies on the choices of treatments and controls, however. For instance, when the research goal is to make inferences for the development of New Urbanism and Smart Growth Communities (called alternative development for simplicity), residents living in traditional neighborhoods are not appropriate treatments because they often differ from those living in alternative development. For instance, the latter tend to be more affluent than the former (Song and Knaap 2003; Dill 2008). The desirable treatments for achieving such a goal are residents currently living in alternative development (Khattak and Rodriguez 2005; Dill 2006).

The choice of controls matters when we explore the ridership bonus of rail transit. Rail transit often replaces bus routes where transit demand is high currently and in the future (Giuliano 2004). Some parallel high-frequency routes in the bus corridor may also be trimmed and cross-town services are added to feed rail transit (Rubin, Moore et al. 1999). Thus, for an evaluation of the impact of a new rail line on transit use of station area residents, it is ideal to have a control corridor whose location context, built environment elements, and demographic profile are similar to the rail transit corridor (Khattak and Rodriguez 2005). The only major difference between the treatment and control is that one is served by rail transit and the other is served by high-frequency buses.

In empirical studies, however, scholars often choose residents in the city/county/region where the rail line is located as controls. Using a 1992-1993 survey to households in multi-family housing complexes in the station areas of Bay Area Rapid Transit (BART), (Cervero 1994) found that rail transit accounted for about 25% of “main trips”, compared to the 7% rail share in the Santa Clara County. (Lund, Cervero et al. 2006) studied travel characteristics of residents in 2003 data from California transit oriented developments (TODs). They concluded that on average station area residents were more likely than residents in surrounding cities to use transit for commute and non-work purposes by factors of 5 and 3.5 times, respectively. As cited in (Cervero, Murphy et al. 2004), station area residents of the Rosslyn-Ballston corridor and the Santa Clara County's light rail corridor commuted by transit four to five times as often as residents countywide (Gerston_&_Associates 1995; Arlington_County 2003). Moreover, a few studies examined transit share using the journey to work census data. (Cervero 1994) stated that in 1990, BART station area residents used rail to get to the workplace far more than residents citywide, with a ratio ranging from 1.6 to 7.2 for different cities. (Renee 2005) investigated travel behavior of 103 TODs in 12 metropolitan regions and concluded that the share of TOD residents who commuted by transit doubled that of regional residents (16.7% vs. 7.1%) in 2000.

These studies illustrate the substantial gaps on transit use between station area residents and residents in the city/county/region as a whole. However, the evidence cannot be directly used to justify the potential ridership bonus of new rail transit. In other words, it does not mean that constructing a rail line will increase station area residents' transit share by three to five times, because residents along the new line have already had a high share of transit use. Therefore, the evidence may mislead policy-makers' decision on the feasibility of rail transit. More importantly, these studies shadow the need for the exact ridership bonus of a new rail line. The consequence is that few, if any, studies have evaluated the impact of rail transit on transit use of station area residents with appropriate controls, and we do not know the extent to which the existing evidence exaggerates the true impact.

Further, the ridership bonus may be due to both rail transit infrastructure and residential self-selection (Cao, Mokhtarian et al. 2009). Many current rail users rode bus or rail transit when they lived in their previous residences or before the rail line was constructed (Baum-Snow and Kahn 2005; Senior 2009). The share of switchers within transit modes sometimes exceeds 50% (Cervero 1994). Therefore, individuals who are transit-dependent or prefer transit may selectively live in the neighborhoods with well-served rail transit, and hence use transit more frequently than those in other areas. This phenomenon is called residential self-selection, which is a confounding factor between the relationships between rail transit infrastructure and transit use. Residential self-selection can account for as much as 40% of the rail ridership bonus (Cervero 2007). Thus, rail transit may not offer regional mobility benefits among a large proportion of station area residents. On the other hand, some station area residents that used transit before may switch back to non-transit modes (Cervero 1994; Knowles 1996; Dill 2008), presumably due to induced demand and triple convergence. Therefore, a claim that a new rail line attracts certain percentage of new transit users overstates its impact because the claim does not consider the attrition of station area and non-station area residents who switch from transit to other modes because of the new line.

Because of residential self-selection, new residents attracted to rail station areas (movers) presumably use transit more frequently than those who reside in the areas before the construction of rail transit (non-movers). However, do the movers ride transit more often than new tenants in the neighborhoods with well-served buses? If there is no apparent difference, the ridership bonus among new residents around rail station areas may reflect a ridership trend in transit-friendly neighborhoods in the region. That is, those who are transit-dependent or prefer transit are attracted to neighborhoods with well-served transit no matter whether the transit is bus or rail. If this is true, rail transit does not offer mobility benefits beyond bus transit. However, there is little empirical evidence for the assumptions in the literature.

4.2 Modeling Approach

This chapter applies propensity score matching (PSM) approach to quantify the differences in transit use between different corridors. The PSM has been widely used to address nonrandom assignment of treatments in the evaluation of social programs (Oakes and Johnson 2006). In the context of land use and transportation, because of residential sorting, residents in one corridor tend to differ from those in other corridors. Therefore, the observed difference in travel behavior between the two groups is confounded by residential self-selection. Statistically, it is a biased estimate of treatment effect.

Conceptually, if we can find an almost "identical" observation in the control group for an observation in the treatment group, this matching is approximately equivalent to the process in which one of the two "same" observations is assigned into a treatment group and the other is assigned into a control group. If we repeat this process for all observations in the treatment group, observations in the matched treatment group should not differ from those in the matched control group. That is, the matching roughly resembles an experiment with random assignment of treatment.

When a treatment group differs in many characteristics from a control group, the matching should be based on a scalar that can integrate all of these characteristics (Rosenbaum and Rubin 1984). The propensity score (PS) is a scalar function that can be used to balance multiple characteristics. The PS in this context is the conditional probability that an individual lives in one type of corridors given her observed characteristics. This probability can be predicted using binary logit models. Using large and small sample theory, (Rosenbaum and Rubin 1983) have proved that "adjustment for the scalar propensity score is sufficient to remove bias due to all observed covariates [characteristics/variables]" (p.41).

In this study, we choose the command "PSMATCH2", with the following options "nonreplacement", "common", and "caliper (0.01)", to implement matching in STATA 11 (Leuven and Sianesi 2003). The PSM process is as follows: First, we develop a binary logit model to predict individuals' probability (or PS) of living in the Hiawatha (treatment) corridor, with demographics being independent variables. Second, we match respondents in the Hiawatha corridor with those in the urban (control) corridors based on the PS. Then, we use "PSTEST" to examine whether demographics are balanced between the matched groups. The following equation was used to calculate the standard difference δ (D'Agostino 1998):

$$\delta = \frac{100(\bar{x}_T - \bar{x}_C)}{\sqrt{\frac{s_T^2 + s_C^2}{2}}}$$

where $\bar{x}_T$ and s_T^2 are the mean and standard deviation of a covariate for the treatment group, respectively; $\bar{x}_C$ and s_C^2 are the mean and standard deviation of a covariate for the control group, respectively. It was suggested that $\delta \leq 10\%$ is an acceptable difference between groups, a rule of thumb in Epidemiology (Oakes and Johnson 2006). If we were not able to successfully balance covariates in the first attempt, we can modify the PS model specification and repeat previous three steps. Specifically, the unbalanced covariate, its high-order form (such as polynomial terms), and its interaction with other variables can enter the PS model until the balance of all covariates is achieved (Rosenbaum and Rubin 1984). If we successfully balance the covariates, the average treatment effect (ATE) is the difference in mean outcomes between the matched treatment and matched control groups (D'Agostino 1998). In this context, it is the impact of rail transit itself on transit use, after controlling for residential self-selection.

4.3 Results and Discussion

The travel behavior variables analyzed in this chapter include use of transit for commute and for non-work purposes. In the survey, respondents were asked to indicate the number of days they used bus/rail to commute in a typical week with good weather, based on a six-point ordinal scale ranging from "Never", "Less than once per month", "1-3 times per month", "Once per week", "2-3 days per week", to "4-5 days per week". They were recoded as approximately "0", "0.5", "2", "4.3", "10.75", and "19.35" times per month, respectively. Respondents were also asked to answer the following question: "In *a typical month with good weather*, how often do you take *public transit* from your home to each of the following places *for purposes other than work/school*?" The seven non-work purposes are shown in Table 4.1. The choice set included "Never", "Less than once per month", "Once or twice per month", "About once every two weeks", "About once per week", and "Two or more times per week". Similarly, they were recoded as "0", "0.5", "1.5", "2.15", "4.3", and "12.9" times per month, respectively.

Table 4.1: Behavioral Differences between the Hiawatha and Urban Control Corridors

	Observed Difference	p-value	PSM ATE	p-value	Control	ATE/Control Ratio
Non-Movers						
A religious or civic building (ex., library)	0.076	0.667	0.042	0.803	0.404	0.10
A service provider (ex., bank, barber)	0.053	0.749	0.054	0.741	0.402	0.13
A store or place to shop	**0.652**	**0.003**	**0.672**	**0.004**	0.463	1.45
A restaurant or coffee place	**0.367**	**0.038**	**0.439**	**0.015**	0.311	1.41
A place for entertainment/recreation	**0.360**	**0.014**	**0.394**	**0.012**	0.371	1.06
A place to exercise (ex., a gym or a park)	0.268	0.168	0.214	0.289	0.353	0.61
To pick up or drop off a passenger	0.194	0.103	0.211	0.099	0.118	1.79
Total non-work trip frequency	**1.970**	**0.029**	**2.025**	**0.033**	2.421	0.84
Total non-work trip probability	**0.234**	**0.000**	**0.243**	**0.000**	0.383	0.63
Commute frequency	**1.488**	**0.027**	1.228	0.070	1.879	0.65
Commute probability	**0.136**	**0.010**	**0.143**	**0.015**	0.264	0.54
Movers						
A religious or civic building (ex., library)	-0.200	0.234	-0.063	0.757	0.559	-0.11
A service provider (ex., bank, barber)	-0.182	0.294	-0.061	0.764	0.583	-0.10
A store or place to shop	-0.001	1.000	0.066	0.803	0.928	0.07
A restaurant or coffee place	-0.069	0.741	0.010	0.968	0.845	0.01
A place for entertainment/recreation	0.072	0.757	0.137	0.617	1.129	0.12
A place to exercise (ex., a gym or a park)	-0.211	0.280	-0.147	0.509	0.576	-0.26
To pick up or drop off a passenger	**-0.327**	**0.016**	-0.152	0.271	0.286	-0.53
Total non-work trip frequency	-0.919	0.395	-0.209	0.865	4.905	-0.04
Total non-work trip probability	**0.184**	**0.000**	**0.161**	**0.002**	0.554	0.29
Commute frequency	0.273	0.704	0.473	0.575	3.863	0.12
Commute probability	0.019	0.704	0.082	0.159	0.315	0.26

4.3.1 Hiawatha and Urban Control Corridors

Table 4.1 compares transit use for various purposes between residents living in the Hiawatha and urban control corridors. Because the Hiawatha LRT may influence movers and non-movers differently, we estimate its impacts separately. First, we explain how to read the table using the purpose of visiting a store or a place to shop as an example. The observed difference among non-movers is 0.652, with a p-value of 0.003. Therefore, on average non-movers in the Hiawatha corridor use transit for shopping significantly more than those in the urban control corridors. The difference, 0.652 trips per month, is a result of both the Hiawatha LRT itself and residential self-selection. The ATE obtained from the PSM is 0.672, with a p-value of 0.004. That is, after controlling for residential self-selection, non-movers in the Hiawatha corridor take 0.672 additional transit trips per month for shopping, compared to those in the urban control corridors, and the difference is statistically significant. The implication is that the Hiawatha LRT increases non-movers' transit use for shopping. Further, the ATE is 1.45 times as large as transit use of matched non-movers in the urban control corridors, which are on average 0.463 trips per month. This implies a practically substantial impact of the Hiawatha LRT.

Similarly, the ATEs for visiting a restaurant or coffee place and a place for entertainment/recreation are 0.439 and 0.394 trips per month, respectively, and both effects are significant. For each purpose, the ATE exceeds current transit use of matched non-movers in the urban control corridors. The ATE for the purpose of picking up or dropping off a passenger is significant at the 0.10 level whereas the ATEs for other purposes are insignificant.

The ATE of total transit use for the seven purposes is 2.025. It implies that when a random nonmover experiences the Hiawatha LRT treatment, we expect s/he increases her/his transit use by 2.025 trips per month. The effect accounts for 84% (=2.025/2.421) of total transit use of matched non-movers in the urban control corridors. Further, we recode trip frequency variables for the seven purposes into seven dummy variables, which indicate whether a respondent has taken transit trips for particular purposes. Specifically, if a respondent reports a transit trip, the dummy variable is coded as "1"; otherwise, it is recoded as "0". Overall, the Hiawatha LRT increases the probability of taking transit: 38.3% of matched non-movers in the urban control corridors have taken transit and 62.6% of matched non-movers in the Hiawatha corridor have used transit.

Non-movers in the Hiawatha corridor are more likely to use transit to commute than those in the urban control corridors. The former uses transit more often than the latter, although the difference in frequency is significant only at the 0.10 level. Both differences are substantial in practice, as shown by the ATE/control ratios of 0.54 and 0.65.

Two observations are worthy noting in Table 4.1. First, all ATEs are positive although some are statistically insignificant. Second, the ATEs can be larger than or smaller than the observed differences. That is, if we do not control for residential self-selection, we may under- or over-estimate the impact of the Hiawatha LRT on transit use. This is consistent with the conceptual analysis in (Cao 2010).

However, when we compare transit use between movers currently living in the Hiawatha and urban control corridors, we find that the ATEs for four of the seven non-work purposes have negative signs although none of them are significant. Moreover, there are no significant differences in transit use for commute, in terms of both frequency and probability. The only significant variable is non-work trip probability for all seven purposes: movers in the Hiawatha corridor are more likely to take transit for non-work travel than those in the urban control corridors although there is no difference in trip frequency. This finding is consistent with (Senior 2009): the LRT attracts former car users but they use it infrequently.

For movers, the observed differences for total non-work travel and commute share the same pattern as the ATEs: the only significant variable is total non-work trip probability. Since the observed differences include self-selection effects, those who are transit-dependent or prefer transit are attracted to neighborhoods with well-served transit no matter whether the transit is bus or rail.

Interestingly, in the urban control corridors, movers are more likely to use transit for both work and non-work trips and use it more often than non-movers (Table 4.2). Therefore, the movers selectively relocate to transit-friendly corridors to enjoy transit accessibility. On the other hand, in the Hiawatha corridor, movers are more likely to use transit for non-work trips than non-movers but there are no differences for the remaining three variables. It seems that residential self-selection is more prevailing in the urban control corridors than in the Hiawatha corridor. Presumably, compared to the urban control corridors, transit-dependent people are less likely to afford to live in the Hiawatha corridor because of the housing premium associated with the LRT (Goetz, Ko et al. 2010).

Table 4.2: Behavioral Differences between Movers and Non-Movers

	Hiawatha			Urban Control		
	Movers	**Non-movers**	**p-value**	**Movers**	**Non-movers**	**p-value**
Total non-work trip frequency	4.51	4.34	0.852	5.11	2.72	0.022
Total non-work trip probability	0.74	0.60	0.001	0.54	0.38	0.001
Commute frequency	3.99	3.47	0.453	3.91	2.20	0.011
Commute probability	0.44	0.41	0.550	0.43	0.29	0.006

4.3.2 Hiawatha and Suburban Control Corridors

To estimate the extent to which using suburban corridors as controls overstates the impact of the Hiawatha LRT on transit use, we apply the PSM to estimate the differences between residents currently living in the Hiawatha and suburban corridors. As shown in Table 4.3, non-movers in the Hiawatha corridor take transit for each of the seven purposes more frequently than non-movers in the suburban corridors. However, all differences become insignificant at the 0.05 level once we control for self-selection. For total non-work trip frequency, non-movers in the Hiawatha corridor use transit about 1.8 times as often as those in the suburban corridors. Further, the former uses transit to get to work about 5.5 times as frequent as the latter. The two statistics between non-movers in the Hiawatha and urban control corridors are 0.84 and 0.65, respectively. Therefore, we will substantially overstate the impact of the Hiawatha LRT on transit use if we use suburban corridors as controls.

Although there are no significant differences in transit use between movers in the Hiawatha and urban control corridors, movers in the Hiawatha corridor take transit more frequently than those in the suburban corridors and almost all ATEs are significant. Overall, movers in the Hiawatha corridor use transit about 3.4 times as many as those in the suburban corridors, and the former uses transit to commute about 1.7 times as often as the latter. Because the ATE presumably eliminates self-selection effect, access to transit does have a positive effect on transit ridership.

4.4 Summary

This chapter adopts a cross-sectional matched-pair design to quantify the impact of the Hiawatha LRT on transit use among residents living along the Hiawatha corridor. Compared to those in the urban control corridors, transit use among non-movers in the Hiawatha corridor increases substantially whereas those moving into the corridor after the opening of the LRT do not show a significant increase. Compared to bus, does LRT increase transit use? The answer is yes for those who choose to stay in the LRT corridor. The increase is evident in both non-work and commute travel. The increase is practically substantial, but it is far below the ridership bonus observed in previous studies (Arlington_County 2003; Lund, Cervero et al. 2006). On the other hand, although new residents are more likely to use transit for non-work purpose, they use it infrequently. Therefore, it is not surprising that there is no difference in trip frequencies between movers in the Hiawatha and urban control corridors.

Table 4.3: Behavior Differences between the Hiawatha and Suburban Control Corridors

	Observed Difference	p-value	PSM ATE	p-value	Control	ATE/Control Ratio
Non-Movers						
A religious or civic building (ex., library)	**0.417**	**0.005**	0.262	0.089	0.066	3.97
A service provider (ex., bank, barber)	**0.321**	**0.034**	0.106	0.093	0.064	1.66
A store or place to shop	**0.783**	**0.001**	0.310	0.075	0.274	1.13
A restaurant or coffee place	**0.413**	**0.019**	0.159	0.194	0.132	1.20
A place for entertainment/recreation	**0.405**	**0.002**	0.220	0.069	0.190	1.16
A place to exercise (ex., a gym or a park)	**0.400**	**0.029**	0.168	0.124	0.033	5.09
To pick up or drop off a passenger	**0.202**	**0.015**	0.168	0.116	0.020	8.40
Total non-work trip frequency	**2.941**	**0.000**	**1.394**	**0.016**	0.779	1.79
Total non-work trip probability	**0.458**	**0.000**	**0.448**	**0.000**	0.144	3.11
Commute frequency	**3.248**	**0.000**	**2.900**	**0.000**	0.528	5.49
Commute probability	**0.347**	**0.000**	**0.330**	**0.000**	0.094	3.51
Movers						
A religious or civic building (ex., library)	**0.336**	**0.016**	**0.203**	**0.008**	0.056	3.63
A service provider (ex., bank, barber)	**0.395**	**0.010**	**0.331**	**0.019**	0.015	22.07
A store or place to shop	**0.547**	**0.026**	**0.458**	**0.023**	0.195	2.35
A restaurant or coffee place	**0.599**	**0.003**	0.283	0.073	0.156	1.81
A place for entertainment/recreation	**0.981**	**0.000**	**0.624**	**0.002**	0.240	2.60
A place to exercise (ex., a gym or a park)	**0.419**	**0.012**	**0.360**	**0.047**	0.005	72.00
To pick up or drop off a passenger	0.037	0.638	**0.034**	**0.006**	0.000	-
Total non-work trip frequency	**3.313**	**0.000**	**2.293**	**0.001**	0.666	3.44
Total non-work trip probability	**0.537**	**0.000**	**0.534**	**0.000**	0.175	3.05
Commute frequency	**2.616**	**0.001**	**2.522**	**0.008**	1.510	1.67
Commute probability	**0.319**	**0.000**	**0.337**	**0.000**	0.116	2.91

Given the insignificant differences among movers, this study offers three lessons if the goal is to facilitate transit use among station area residents. First, because transit ridership depends on the attractiveness of activities around transit stations, planners need to think about development potential when they plan an LRT route. The Hiawatha LRT has not had significant impacts on land use development since it opened in 2004. The line was built along an industrial corridor and existing commercial establishments if any are oriented toward automobiles. The presence of industrial facilities adversely impacts the attractiveness of adjacent lands. Although recent station area plans make these uses incompatible, it takes years or even decades for them to relocate/change. Further, stations areas were designed as transit nodes instead of vibrant places. They are not activity destinations in nature.

Second, planners need to connect residential neighborhoods and rail stations to maximize ridership. A pedestrian-friendly environment is important for residents to access to station areas and take transit. The Hiawatha Avenue is a state trunk highway and carries heavy traffic: its speed limit is 40 miles per hour and there are on average 29,000 vehicles daily near the 38th Street station. That is, the street was designed for auto traffic instead of pedestrians, bicyclists, and transit users. The state trunk highway, industrial sites, and rail tracks serving the sites also separate the Hiawatha LRT and residential neighborhoods on the eastside. These great lower the walkability of station areas.

Third, affordable housing and displacement prevention are essential to attract and sustain heavy transit users. The vast majority of new housing units in Minneapolis neighborhoods are market rate condominiums and rental housing. They are for choice riders. Since choice riders use transit less frequently than captive riders (Pucher and Renee 2003), it is not surprising that movers in the Hiawatha and urban control corridors have similar level of transit use. Moreover, captive riders may have been priced out of the Hiawatha station areas as housing property values rose in response to access to LRT (Goetz, Ko et al. 2010). In other words, the LRT may push out residents who use transit heavily and replace them with new choice riders that exhibit infrequent transit usage. Therefore, planners should establish affordable housing goals, keep affordable housing development close to stations, and develop programs to reduce the displacement of residents (CTOD 2008).

On the other hand, the Hiawatha LRT may affect travel behavior in a way that this study could not capture. About 1,000 housing units have been built or been under construction in Minneapolis neighborhoods surrounding the Hiawatha LRT during 2000-2012. The development will not happen without the LRT. New residents may have moved into the LRT corridor from transit-inaccessible places; thus even though movers in urban corridors show similar transit use, the Hiawatha LRT allows movers who prefer LRT but have no options previously to replace car trips with new transit trips now.

5. LIGHT RAIL TRANSIT, BUILT ENVIRONMENT AND PEDESTRIAN TRAVEL

Policymakers and planners have increasingly been turning to active travel - walking and bicycling - as a transportation alternative in order to promote healthy lifestyles and induce mode shift away from the automobile. The recently completed Federal Nonmotorized Transportation Pilot Program evaluated the effects of targeted investments in nonmotorized planning, infrastructure, and education in four pilot cities on rates of walking and bicycling (FHWA 2012). Numerous studies have identified benefits associated with pedestrian travel. Individuals experience improved physical health outcomes, social cohesion, and transportation satisfaction (Litman 2010). Further, society benefits because walking causes no congestion, air pollution, or noise pollution and requires no dedicated parking space or fossil fuels (Litman 2003; Campbell and Wittgens 2004).

Investments in new rail transit projects may increase active travel. Major transit infrastructure projects bring substantial investment,, both in the rail infrastructure itself and in built environment improvements in the corridor to facilitate walking (among other modes) connections to the new rail line. Some studies identified a direct relationship between transit use and physical activity due to the typical means of accessing transit stations: walking (Brown and Werner 2007; MacDonald, Stokes et al. 2010; Lachapelle and Noland 2012). Rail transit investment may also have a carryover effect on walking behavior (Brown and Werner 2007; Lachapelle and Noland 2012). As more and more people start to walk to rail stations, they become familiar with the environment they walk: the quality of walking route and the amenities along the route. Conceptually, this may in turn promote walking for other purposes such as exercise and shopping among rail transit users. (Ewing and Cervero 2010) found that transit ridership is associated with corridor improvements on, specifically, proximity to transit, street network design, and land use diversity. Many of the built environment characteristics commonly associated with transit ridership are expected to influence pedestrian travel behavior: density brings destinations closer together, diversity provides broader access to goods and services nearby, and infrastructure network design provides connectivity between origins and destinations by whatever the chosen mode. Therefore, if there is a significant relationship between transit corridor improvements and pedestrian travel, policymakers could capitalize on rail transit projects to maximize the potential for increases in pedestrian travel while the corridor is already undergoing improvements.

However, a limited number of studies have explored the relationship between the built environment around rail transit corridors and the carryover walking trips, and few have considered the confounding influence of residential self-selection. The purpose of this chapter is to identify and measure the carryover effects of light rail transit (LRT) and associated built environment attributes on pedestrian travel, above and beyond the walking that is implicit in accessing the transit station from one's home or destination. Specifically, we use negative binomial regression to model frequencies of recreational walking (strolling) and utilitarian walking trips (to the store) near the Hiawatha Light Rail Line in Minneapolis, MN. We use a set of demographic characteristics, travel attitudes, residential preferences, subjective and objective built environment measures to predict pedestrian travel.

5.1 Background

Rail transit impacts walking behavior through two primary mechanisms: direct effect, and carryover effect from environment and personal factors (Brown and Werner 2007). Direct effect refers to people using walking as their primary mode for accessing transit facilities. Additionally, recent literature on transit and walking suggests a carryover effect: the presence of transit may be a catalyst for additional walking trips beyond access to transit among transit users and transit corridor residents. As a person walks more to use the transit facility, they discover new destinations near their home; this environmental factor empowers people to make additional walking trips. Personal factors, such as needing to complete an errand during one's lunch break when they took transit to work that "car free" day, also motivate additional walking.

5.1.1 The Impacts of Built Environment Characteristics

(Ewing and Cervero 2010), in their meta-analysis of built environment impacts on travel behavior, computed elasticities for both walking and transit use with respect to several categories of built environment variables. They found that many of the same density, diversity, and design factors support both walking and transit trips. Notably, while they found transit to be twice as sensitive as walking to proximity to a transit stop, both walking and transit use have positive elasticities with transit stop proximity (0.29 and 0.15 respectively). Ewing and Cervero's findings call into question the underlying relationship between LRT facilities and walking trips: does transit itself actually encourage additional walking trips, or are observed relationships between transit use and additional walking trips simply a function of the same built environment factors supporting both modes?

5.1.2 The Impacts of Environment and Personal Factors

(Brown and Werner 2007) used a quasi-experimental study design to measure travel behavior impacts of adding a new LRT stop along an existing corridor in Salt Lake City. Objective physical activity measures were collected using accelerometers before and after the stop opened, and participants reported which physical activity occurred on a walking trip to a transit stop and which were walking trips to other destinations. The authors observed a significant increase in transit ridership in response to the new stop. They also described an increase in walking trips not associated with transit station access and speculated the impacts of environment and personal factors.

(MacDonald, Stokes et al. 2010) employed a longitudinal study design to measure changes in self-reported health indicators (body mass index and attainment of recommended physical activity levels) in response to the opening of a new LRT line in Charlotte. They found that transit users lost weight and were more likely to attain the recommended activity levels from walking after the LRT opened. Their study did not distinguish between walking for station access and additional walking trips, though they inferred that this benefit could plausibly come strictly from walking to access the transit station without additional carryover walking trips.

In contrast with (MacDonald, Stokes et al. 2010), (Lachapelle and Noland 2012) modeled walking activity as a function of primary commute mode choice based on a 2009 travel behavior survey in New Jersey, controlling for demographics and self-reported neighborhood destinations.

They found that commuting by transit had a positive and statistically significant relationship with walking, and the effect was nearly identical between people who walked to the transit station and people who used park-and-ride or kiss-and-ride. This outcome suggests a strong effect from personal factors because the respondents who used a car to access the transit stop experience almost as much physical activity bonus as those who walked to the station. The authors also found that transit commuting had a positive and statistically significant relationship with walking for personal errands and grocery shopping, in addition to station access.

5.1.3 Implications and Goals

While previous studies demonstrate a relationship between transit facilities and walking for various purposes, they did not thoroughly explore the contributions of residential preferences, travel attitudes, and built environment characteristics to the observed association between increased transit use and additional walking trips. Environment and personal factors are a function of these residential preferences, travel attitudes, and built environment characteristics. The extent to which people can identify new destinations while walking to the station depends heavily on the prevalence of destinations between the person's home and the transit facility. Residents do not make travel decisions in a vacuum; travel attitudes, such as preference for walking or good sidewalk facilities, may make people more likely to make additional walking trips on their lunch break rather than consolidating their errands into car trips at another time. Therefore, measuring travel attitudes, residential preferences, and built environment characteristics is essential for understanding how these environmental and personal factors influence walking around transit facilities. (Brown and Werner 2007) and (MacDonald, Stokes et al. 2010) do not directly measure travel attitudes and residential preferences and test their effects on the relationship between walking and transit in their models. (Lachapelle and Noland 2012) models did not include measures for built environment factors, residential preferences, or travel attitudes.

Longitudinal studies hold residential preferences and travel attitudes constant by measuring travel behavior in the same individuals before and after the LRT treatment. But they do not necessarily measure what role those factors play in explaining changes in walking behavior. Individual travel attitudes may moderate a participant's sensitivity to a new transit facility treatment through an interaction effect. So directly measuring residential preferences and travel attitudes is essential to disentangle their effects from built environment factors on walking and transit.

These gaps in our understanding of how transit availability and use affect walking behavior have important policy implications. Funding for nonmotorized transportation and transit alike are targeted toward increasing mode share of that particular mode and shifting trips away from private autos. If transit facilities interact with environment and personal factors to increase walking behavior, this phenomenon would shift cost-benefit analysis and travel forecasts. If we find that the observed effect is primarily a function of built environment characteristics that are commonly shared between transit- and pedestrian-friendly places, then supporting pedestrian improvements around LRT facilities and compatible land uses may be a useful strategy for increasing walking. If travel attitudes and residential preferences are the primary drivers of increased walking trips within the transit corridor, the policy discussion should include strategies to provide adequate housing supply for people with these preferences to move into the transit corridor. Understanding these dynamics may be essential for planning transportation network improvements that serve users and achieve the desired transportation, environmental, and health outcomes.

Through this study we address these gaps in the literature about the relationship between transit facilities and walking trips in hopes of addressing these policy questions. This study specifically considers trips for which the primary mode is walking, thereby removing direct effects of transit station access and focusing exclusively on the potential for carryover effects. We control for residential preferences and travel attitudes directly through survey questions that elicit these individual traits. We also model the effects of both perceived built environment and objective measures around the respondent's home to address questions about whether transit causes carryover effects and how built environment features enable walking trips.

5.2 Model Development

The dependent variables, shown in Table 5.1, are the number of days within the past 7 days on which the respondent walked to the store (utilitarian walking) or went for a stroll around the neighborhood (recreational walking). In the sample, 604 (47.2%) reported walking to the store at least one day in the past week, and the mean number of days on which the respondent walked to the store was 2.1 for walkers. Strolling trips were much more common than trips walking to the store: 983 (77.0%) respondents reported going for a stroll at least one day in the past week, and of these respondents, they went for a stroll on an average of 3.8 days out of the past 7. ANOVA tests reveal statistically significant differences ($p<0.05$) across corridors in the average number of days in the past week on which the respondent took a stroll or walked to the store and in the percentage of the sample strolling or walking to the store on at least one day in the past 7. Bonferroni post-hoc tests show that these differences are much more pronounced between corridors for store trips than strolling trips. There were no statistically significant differences across corridors for the average number of days with walking trips among respondents who took at least one walking trip; this was true for both store and stroll trips.

Table 5.1: Dependent Variables by Corridor

	P Value	Hiawatha	Bloomington	Nicollet	Coon Rapids	Burnsville
Strolling Trips						
Mean days strolling	0.037	2.91	2.84	2.84	2.42	2.41
Pct strolling at least once	0.033	79 %[BU]	77 %	81 %[BU]	75 %	69 %[HI, NI]
Mean for strollers	0.226	3.68	3.67	3.51	3.22	3.52
Store Trips						
Mean days walking	0.000	1.23[NI, CR, BU]	1.09[NI, CR, BU]	1.51[HI, BL, CR, BU]	0.36[HI, BL, NI]	0.43[HI, BL, NI]
Pct walking at least once	0.000	55 %[CR, BU]	56 %[CR, BU]	64 %[CR, BU]	19 %[HI, BL, NI]	22 %[HI, BL, NI]
Mean for walkers	0.148	2.04	1.96	2.35	1.88	1.93

Bonferroni post-hoc tests (α = 0.05):
[HI] = Statistically different from Hiawatha
[BL] = Statistically different from Bloomington
[NI] = Statistically different from Nicollet
[CR] = Statistically different from Coon Rapids
[BU] = Statistically different from Burnsville

This chapter employs negative binomial regression to model the frequencies of utilitarian and recreational walking trips. Since they are non-negative counts of the days on which the respondent took a utilitarian or recreational walking trip, Poisson-family regressions are appropriate for modeling count data. We selected negative binomial regression here because we assumed that the variances of dependent variables exceed their respective means. Regression results presented in the next section show positive and statistically significant dispersion parameters, confirming that negative binomial model is an appropriate choice for these data. Refer to (Cao, Handy et al. 2006) for a description of the modeling approach.

The models isolate the effects of perceived and objective neighborhood characteristics on utilitarian and recreational walking behavior after controlling for residential preferences, travel attitudes, and demographic characteristics. In the survey, respondents were asked to indicate how true 30 characteristics are for their neighborhood, on a four-point scale from "not at all true" (1) to "entirely true" (4). The 30 statements cover attributes associated with living units, land use and transportation systems, safety, social environment, and so on. The characteristics of these neighborhoods as perceived by survey respondents reflect fundamental differences in neighborhood design. Also the importance of these items to respondents when/if they were looking for a new place to live were measured on a four-point scale from "not at all important" (1) to "extremely important" (4). The comparison of individuals' perceived neighborhood characteristics for their current residence and their neighborhood characteristic preferences indicates how well their current neighborhoods meet their preferences. We used bivariate correlation to identify variables for inclusion in preliminary modeling (not shown) and tested preference and perception variables measuring sidewalk coverage, street lighting, social interaction, proximity to shopping, work, and other destinations, and general safety of neighborhood for walking or playing. Significant variables that remained in the final model were proximity to shopping for modeling utilitarian walking and preference for safe neighborhoods for walking for modeling recreational walking.

Again, the objective built environment characteristics include measures related to density (such as population density and housing density), diversity (such as entropy indices of land use mix and business mix), design (such as number of four/five-way intersections and cul-de-sacs), distance to activities (such as gym and shops), and access to transit (distance to the closest station and stop density). Preliminary modeling tested all of these different objective built environment measures, iteratively removing insignificant and redundant variables. The variables significant in this study, included in the final model, are measured as follows: (1) population density, measured in the number of people per acre for all census tracts intersecting the network distance buffer around the respondent's home, (2) percent of land use within the buffer that is classified as "Commercial" as of 2010, and (3) number of interruptions (cul-de-sacs or dead ends) within the buffer, measured using a spatial dataset of local streets. The objective built environment measures capture the widely cited "three D's" that are associated with travel demand: population density, land use diversity in the form of a mix of commercial uses near the respondent's residence, and street network design in the form of presence or absence of network interruptions (Ewing and Cervero 2010). Although these characteristics were measured within ¼, ½, and 1 mile buffers, the model shows that the measures of the ¼ mile buffer are the most powerful in explaining difference in walking behavior.

To measure attitudes regarding travel, the survey asked respondents whether they agreed or disagreed with a series of 21 statements on a 5-point scale from "strongly disagree" (1) to "strongly agree" (5). Factor analysis was then used to dimensions extract the fundamental spanned by these 21 items, since some of the items are highly correlated. As shown in Table 5.2, seven underlying dimensions were identified: pro-drive, pro-walk, pro-bike, pro-transit, safety of car, status of car and pro-travel. Pro-walk was selected for use in both models to control for travel attitudes. Pro-transit was considered to control for self-selection into transit-oriented neighborhoods, but it was only significant in the store model. Safety of car had a statistically significant relationship with strolling and was included in the model. An interaction variable between pro-walk travel attitudes and the presence of LRT was not significant.

5.3 Results and Discussion

5.3.1 Model Fit

The results from the two models are presented in Table 5.3 and Table 5.4. Each model is presented incrementally to show the effects of demographics, corridors, travel and residential preferences, perceived neighborhood characteristics, and objective built environment characteristics. The Pseudo-R^2 for the full models is 0.123 for walking trips to the store and 0.046 for strolling trips. They are comparable to other negative binomial models of walking travel behavior (Cao, Handy et al. 2006; Joh, Nguyen et al. 2012). Further, it suggests that walking trips to the store is much better predicted by our survey data and objective built environment measures than strolling trips, also consistent with previous studies of walking using negative binomial models (Cao, Handy et al. 2006; Handy, Cao et al. 2006). The stroll model's Pseudo-R^2 improves substantially between the demographics only model and the preferences model, and the remaining iterations of this model only add marginal improvements. Dummy variables indicating different corridors were insignificant in the model after controlling for other factors, so they were removed from the final model. The store model improves considerably with the addition of corridor and preferences, with smaller increases after adding perceptions and objective built environment measures.

5.3.2 Store Model

Demographics, travel and residential preferences, perceived neighborhood characteristics, and objective built environment measures are significant at the 0.05 level in modeling the days in a week on which the respondent walked to the store. As expected, pro-walk attitudes and residential preference for having shopping areas within walking distance were positively and significantly associated with utilitarian walking. Pro-transit attitudes, which we included to control for self-selection into the Hiawatha Light Rail corridor or urban control corridors due to a preference for transit accessibility, were also associated with walking. Respondents who have the preferences were more likely to reside in urban corridors. These results suggest a residential self-selection effect: people who prefer walking move into walkable neighborhoods and consequently walk more. Controlling for this effect helps us isolate the effect of built environment characteristics on walking.

Even after controlling for both travel attitudes and residential preferences, both perceptions of proximity to shopping areas and the objective measure of commercial land use within ¼ mile were positively and significantly associated with utilitarian walking. This highlights the importance of the built environment even after controlling for self-selection into neighborhoods with walkable characteristics.

Table 5.2: Pattern Matrix for Travel Attitudes

	Safety of car	Status of car	Pro-travel	Pro-drive	Pro-transit	Pro-bike	Pro-walk
Traveling by car is safer overall than walking.	0.748						
Traveling my car is safer overall than taking transit.	0.582						
Traveling by car is safer overall than riding a bicycle.	0.335					-0.308	
It does not matter to me which type of car I drive.		-0.642					
To me, the car is nothing more than a convenient way to get around.		-0.601					
To me, the car is a status symbol.		0.324		0.341			
Travel time is generally wasted time.			-0.615				
The only good thing about traveling is arriving at your destination.			-0.544				
Getting there is half the fun.			0.446	0.384			
I like to drive just for fun.				0.692			
I like driving.				0.665			
I feel free and independent if I drive.				0.491			
I like taking transit.					0.754		
Public transit can sometimes be easier for me than driving.					0.737		
I prefer to take transit rather than drive whenever possible.					0.711		
I prefer to bike rather than drive whenever possible.						0.846	
Biking can sometimes be easier for me than driving.						0.829	
I like riding a bike.						0.783	
I prefer to walk rather than drive whenever possible.							0.734
I like walking.							0.650
Walking can sometimes be easier for me than driving.							0.546

Note: The method was Principal axis factoring with Oblimin with Kaiser Normalization. Loadings smaller than 0.300 were suppressed.

Table 5.3: Modeling Walking to the Store

	Demographics		Corridor		Preferences		Perceptions		Final Model: Built Environment		
	Coefficient	p value	Coefficient	p value	Coefficient	p value	Coefficient	p value	Coefficient	p value	Incidence Rate Ratio
Constant	1.320	0.000	1.366	0.000	0.233	0.287	-0.372	0.113	-0.837	0.001	
Demographics											
Limitation on walking	-1.356	0.000	-1.290	0.000	-0.882	0.000	-0.796	0.001	-0.794	0.001	0.452
Household with children	0.256	0.006	0.305	0.001	0.309	0.000	0.247	0.004	0.237	0.005	1.267
Female	-0.107	0.202	-0.129	0.108	-0.171	0.026	-0.176	0.019	-0.171	0.022	0.843
Driver License	-1.106	0.000	-0.975	0.000	-0.932	0.000	-0.863	0.000	-0.819	0.000	0.441
Income	-0.056	0.004	-0.067	0.000	-0.058	0.001	-0.050	0.005	-0.031	0.080	0.969
Corridor											
Hiawatha	(base case)		(base case)		(base case)		(base case)		(base case)		
Bloomington			-0.012	0.912	0.125	0.215	0.129	0.194	0.022	0.832	1.022
Nicollet			0.346	0.001	0.346	0.001	0.330	0.001	0.114	0.312	1.121
Coon Rapids			-1.095	0.000	-0.574	0.001	-0.443	0.007	-0.124	0.490	0.883
Burnsville			-0.884	0.000	-0.564	0.000	-0.569	0.000	-0.245	0.164	0.783
Preferences											
Pro-walk travel attitudes					0.275	0.000	0.251	0.000	0.258	0.000	1.294
Pro-transit travel attitudes					0.143	0.000	0.144	0.000	0.136	0.000	1.146
Preference for shopping within walking distance					0.287	0.000	0.206	0.000	0.214	0.000	1.239
Perceptions											
Perception of shopping within walking distance							0.258	0.000	0.234	0.000	1.264
Built Environment											
Commercial Land Use									1.425	0.008	4.158
Population Density									0.033	0.001	1.034
Number of cul-de-sacs									-0.152	0.010	0.859
Dispersion Parameter	0.938	0.000	0.719	0.000	0.489	0.000	0.413	0.000	0.376	0.000	
Number of observations	1211		1211		1198		1191		1191		
Pseudo R^2	0.0288		0.0621		0.1058		0.1185		0.1266		

Table 5.4: Modeling Strolling

	Demographics		Preferences		Perceptions		Final Model: Built Environment		
	Coeff.	p value	Coeff.	p value	Coeff.	p value	Coeff.	p value	Incidence Rate Ratio
Constant	0.907	0.000	0.370	0.007	0.053	0.746	0.057	0.727	
Demographics									
Limitation on walking	-1.060	0.000	-0.740	0.000	-0.715	0.000	-0.714	0.000	0.490
Household with children	0.236	0.000	0.180	0.001	0.180	0.001	0.179	0.001	1.196
Female	0.178	0.001	0.123	0.011	0.144	0.003	0.147	0.003	1.158
Preferences									
Pro-walk travel attitudes			0.235	0.000	0.232	0.000	0.227	0.000	1.255
Concern that cars are safer than walking			-0.083	0.000	-0.075	0.000	-0.074	0.001	0.929
Preference for neighborhood that is safe for walking			0.141	0.000	0.120	0.001	0.119	0.001	1.126
Perceptions									
Perception that neighborhood is safe for walking					0.120	0.000	0.127	0.000	1.135
Built Environment									
Number of cul-de-sacs							-0.044	0.052	0.957
Dispersion Parameter	0.443	0.000	0.330	0.000	0.322	0.000	0.319	0.000	
Number of observations	1239		1226		1219		1219		
Pseudo R^2	0.0161		0.0434		0.0455		0.0463		

Population density and the number of network interruptions within ¼ mile of the respondent's address are also significantly associated with walking. Denser environments facilitate walking, while cul-de-sacs and dead ends break up the street network, causing lengthy detours from a straight line shortest path and reducing the overall size and scope of the ¼ mile network distance buffer.

While the Nicollet control corridor had a higher frequency of store walking trips than Hiawatha, this difference disappeared after controlling for built environment measures in the model. In the final model, corridor was not a significant predictor of utilitarian walking.

5.3.3 Stroll Model

Like the store model, most of the demographic variables performed as expected. The relationship between gender and recreational walking is positive in this model, indicating that women on average stroll more than men after controlling for other factors. While it differs from the results in the store model and other research on utilitarian pedestrian travel, this finding is reasonable. Women receive more health- and fitness-related messaging than men and may be more likely to walk for exercise.

Pro-walk travel attitudes were positively and significantly associated with strolling trips. The car safety travel attitude factor, measuring whether the respondent believed traveling by car was overall safer than other modes including walking, was negatively associated with recreational walking trips. The significance of this variable in the strolling model but not the store model suggests that recreational walking trips are more sensitive to relative safety concerns. The positive and significant relationship between residential preferences for safe neighborhoods for walking and recreational walking trips reinforces this idea.

Number of network interruptions was the only objective built environment variable that explained recreational walking behavior, with a p-value of 0.052. Like the store model, the number of cul-de-sacs and dead end streets within a quarter mile walking distance buffer is negatively associated with walking behavior. By interrupting the street network, they shrink the areas that can be accessed within a quarter mile walk.

Figure 5.1 shows the prevalence of network interruptions in the Nicollet and Hiawatha Corridors. The street grid is well-connected across Nicollet Avenue, but many of the minor streets terminate before Hiawatha Avenue, forcing a pedestrian to walk out to a major street if they need to access or cross the corridor.

Corridor variables were not significant at all in this model.

Figure 5.1: Network Interruptions in Nicollet and Hiawatha Corridors

5.4 Summary

This chapter evaluated the relationship between light rail corridors and pedestrian travel behavior. In general, travel attitudes and residential preferences were strong predictors of both utilitarian and recreational walking. Our negative binomial models found significant effects of built environment characteristics on walking even after controlling for demographics, travel attitudes, and residential preferences. Utilitarian walking (trips to the store) was better explained by the model and much more sensitive to the built environment than recreational walking (strolling). The results can be used to target funding for nonmotorized infrastructure as well as maximize the impact of transit corridor project investments on pedestrian travel behavior.

The corridor variables were not significant in either model, suggesting that LRT and bus have a similar impact on utilitarian walking trips after controlling for built environment characteristics. In this case, the urban control corridors, especially the Nicollet Avenue corridor, had more commercial areas, fewer industrial areas, and better street network connectivity. Controlling for these factors erased Nicollet's initial advantage in walking trips. This supports the idea that built environment improvements along new LRT corridors are crucial for enabling walking. Since walking is a primary mode for accessing transit facilities, making these corridor improvements that support walking should be beneficial for transit riders and ridership levels.

Both perceived and objectively measured proximity to commercial areas are essential for pedestrian shopping trips. Even after controlling for demographics, travel attitudes and residential preference for shopping areas within walking distance, each percentage point increase in commercial land use was associated with an increase of 4.18 % in the average number of days within the past week on which the respondent walked to the store. Additionally, one additional scale point indicating perception of shopping areas within walking distance was associated with an increase of 1.26% in days walking to the store. Thus if planners hope to maximize the potential for transit corridor improvements to increase walking trips, areas within the corridor should be zoned to allow land use diversity and close proximity between residential and commercial uses.

One of the possible mechanisms by which transit causes carryover walking trips is through environmental factors: transit users develop new perceptions about their neighborhood by walking to the transit station. These station access walking trips help transit users find new destinations and build walking into their regular routines. If the surrounding environment lacks walking destinations or features that make walking a comfortable, pleasant experience, there may be fewer opportunities for the station access trips to change transit riders' perceptions about walking. Thus the lack of a supportive built environment may block the possible carryover effects of LRT on walking attributable to environmental factors. Conversely, it may be possible to educate riders and residents about nearby destinations and walkability throughout the neighborhood in order to increase perception of destinations and encourage walking trips. Transit station maps could highlight local shopping areas and services within station areas to increase transit users' awareness of what other destinations are within their neighborhood and only a short walking distance away. Public health campaigns could publish local walking maps for each neighborhood to highlight enhanced pedestrian facilities and local walkable destinations to encourage strolling and utilitarian walking alike.

Adequate density and a continuous street grid, also significant factors in the model, work together to magnify the benefit of proximity to commercial land use by bringing more people into a short walk's distance of the commercial areas without excessive detours due to network interruptions (cul-de-sacs and dead ends). Each additional network interruption is associated with a decrease in the number of days in the past week the respondent walked to the store by a factor of 0.14 (1 - 0.86). Further, each cul-de-sac or dead-end street is associated with a weaker but still significant decrease in strolling frequency by a factor of 0.04 (1 - 0.96). In this study, residents in the Hiawatha corridor had an average of 0.23 network interruptions within a quarter mile walk from their home, compared to 0.14 for Bloomington and 0.07 for Nicollet. While the Hiawatha light rail line provides great transit connectivity to Downtown Minneapolis, the MSP Airport, and the Mall of America, it is also a major factor in these street network discontinuities.

Most east-west local streets in the Hiawatha corridor terminate with a dead end rather than cross this transit facility and the major arterial it parallels, diverting travelers north or south to the nearest major collector in order to cross Hiawatha. Careful rail transit planning should include street network connections across the facility, not simply to the facility, in order to maximize potential for walking trips from the transit investment.

Demographic factors, such as lack of a driver license and having a lower income, were still predictive of increased utilitarian pedestrian trips even after controlling for preferences, perceptions, and the built environment. These significant results are a critical reminder that transportation investments shouldn't simply be designed to change people's behavior; they are tools to improve accessibility for people who already use these modes. Major transit projects must demonstrate under Title VI that the investments do not have discriminatory impacts on residents living in predominately minority areas or in predominately low-income areas. Wrapping pedestrian improvements into these larger transit projects may facilitate their equitable distribution. Affordable housing and transit-oriented development provide opportunities for people who value walking to move into corridors that support their transportation choices and needs.

6. CONCLUSIONS

Using the Hiawatha LRT in Minneapolis as a case study, this project examines transportation effect of transitways. In this project, we administered a self-designed survey, informed by the literature, in five corridors (the Hiawatha corridor, two urban control corridors, and two suburban control corridors) in the Twin Cities in 2011. The survey measured respondents' preferences for housing and neighborhood characteristics, their perceptions of the characteristics, their daily travel, their travel-related attitudes, and their demographic characteristics. Following the survey, we also identified objective built environment characteristics around each respondent's residence. The project consists of three sets of empirical analyses. The remainder of this chapter briefly summarizes the motivation, method, and results of the three analyses. Refer to the corresponding chapters for specific implications of the results. It is worth noting that this study focuses on travel behavior among station area residents but does not consider distant riders who access to LRT stations by bike, connector or car.

LRT has been touted as an effective way to increase ridership. However, not all residents move to LRT corridors for the quality of transit service and access to transit. Chapter 3 explores the characteristics of station area residents, the reasons of moving to the LRT corridor, and their association with transit use. We find that there are few differences in residential preferences between urban residents who live close to or far from the LRT, except their preferences for transit access and quality. Further, although Hiawatha residents strongly prefer transit and the preferences are associated with some demographic characteristics, there are no significant differences in demographics and transit use between Hiawatha and urban control residents. This chapter also finds the evidence of residential self-selection

New rail transits often replace busy bus corridors in the U.S. (Giuliano 2004). When implying their ridership bonus, previous studies often choose the city/county/region as control groups, rather than comparable corridors without rail, and hence overstate their impacts. In Chapter 4, we employ propensity score matching to explore the impacts of Hiawatha LRT on transit use. We find that compared to residents in similar urban corridors, LRT promotes transit use of residents who have moved to the corridor before its opening, whereas Hiawatha residents and urban control residents moving into the corridors after its opening show similar transit use. Thus, besides LRT, land use and transportation policies are necessary to promote transit use in the Hiawatha corridor. On the other hand, the Hiawatha LRT enables new development in urban neighborhoods and the new tenants use transit like their peer urban residents.

It is worth noting that this study focuses on travel behavior among station area residents but does not consider distant riders who access LRT stations by connectors or cars. Park and riders are major patrons of rail transit. This may understate the impact of LRT on transit use. On the other hand, rail transit is likely to spur sprawl type of development (Israel and Cohen-Blankshtain 2010), which in turn undermines overall transit use in the region.

Planners have increasingly been turning to active travel to reduce auto dependence and promote physical activity. It is evident that rail transit promotes walking access to stations associated with increased transit ridership. However, few studies focus on the carryover effect of rail transit and associated built environment in the corridor on pedestrian travel for other purposes. Chapter

5 explores the effects of light rail transit and built environment attributes on the frequencies of walking to the store and strolling. Results from negative binomial regression showed that the Hiawatha LRT does not have a separate effect on pedestrian travel, after controlling for all other factors. On the other hand, after controlling for demographics, travel attitudes, and residential preferences, the frequency of walking to the store is significantly associated with population density, proximity to commercial land use, and street network interruptions. Further, strolling frequency is associated with street network interruptions. Because the built environment characteristics are associated with the Hiawatha LRT, the findings carry important implications for planners to capitalize on light rail projects.

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