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Understanding Transportation Impacts of Transitways:
Demographic and Behavioral Differences Between Transitway Riders and Other Transit Riders

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To improve mobility, Metropolitan Council has proposed a network of dedicated transitways in the 2030 Transportation Policy Plan. This project studied the profile of transit riders in the Twin Cities and explored environmental factors that influence mode choice of access to transitways, using the 2005 Metropolitan Council Transit Rider Survey. We found the Hiawatha Light Rail Transit (LRT) balances efficiency by serving choice riders and equity through promoting reverse commute and serving captive riders. The LRT has also facilitated the formation of a multi-modal transportation system by promoting mode mixing and encouraging transfers. More importantly, travel shed analysis of several transit routes showed the LRT has a much broader influence on the regional transportation network than local buses and express services.

Multinomial Logit models for access mode of the LRT confirmed that riders' demographics, trip characteristics, built environment and social environment factors around LRT stations affect their access modes. Among them, the distance from trip origin to LRT stations is the dominant factor; the impacts of built environment elements were equivalent to those of riders' demographics and trip characteristics, whereas the effects of social environment factors were the weakest. The results suggest if the goal is to maximize the number accessing transitways from existing bus services, we should increase the coverage of feeder services, increase street connectivity and promote mixed-use development. If the goal is to attract choice riders in areas where walking and local transit are not options, more park and ride facilities should be provided.

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Understanding Transportation Impacts of Transitways: Demographic and Behavioral Differences between Transitway Riders and Other Transit Riders

Final Report

Prepared by

Xinyu (Jason) Cao
Rachel Jordan

Hubert H. Humphrey Institute of Public Affairs
University of Minnesota

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The program is supported with funding from Anoka County, the University of Minnesota's Center for Transportation Studies (CTS), Hennepin County (with funding from the Federal Transit Administration (FTA)), the Itasca Group, the Metropolitan Council, the Minnesota Department of Transportation, Ramsey County, the University of Minnesota's University Metropolitan Consortium, and Washington County.

Program coordination is provided by CTS and the State and Local Policy Program at the Humphrey Institute of Public Affairs and is conducted in cooperation with the University of Minnesota's Center for Urban and Regional Affairs, the City of Minneapolis, the City of St. Paul, Dakota County, and the FTA.

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EXECUTIVE SUMMARY

To improve mobility, Metropolitan Council has proposed a network of dedicated transitways in the 2030 Transportation Policy Plan. Because these transitways are significant transportation investments, it is imperative for legislators, planners, and the public to know whether transitways have provided measurable transportation and economic benefits. As the first step in identifying transportation impacts, this project studied the profile of transit riders in the Twin Cities and explored environmental factors that influence mode choice of access to transitways (the Hiawatha Light Rail Transit), using the 2005 Metropolitan Council Transit Rider Survey.

We classified transit services in the region into four categories: Premium Express, Express Bus, LRT, and Local Bus. Generally, we found that premium express had the highest percentage of choice riders (those who have a driver's license and have cars in the household) and the Hiawatha LRT ranked third, with 59% of users being choice riders. On the other hand, the LRT balances efficiency by serving choice riders and equity through promoting reverse commute and serving captive riders (those who do not have a driver's license or have no cars in the household). The LRT has facilitated the formation of a multi-modal transportation system by promoting mode mixing and encouraging transfer between the LRT and other types of transit services.

More importantly, travel shed analysis of several transit routes has showed that the LRT has a much broader influence on the regional transportation network than local buses and express services: local buses mainly serve a narrow corridor along the route; express services serve riders from limited communities at the suburban end; the LRT serves the Hiawatha corridor but also attracts riders from the whole region. In other words, the LRT plays an important role in improving regional accessibility. Further, an overlay of travel sheds for the existing buses along University Avenue shows great potential for the Central Corridor in promoting regional accessibility. Note that the data were collected not in a particular day but over a few months.

Regarding mode choice of access to transit, we found that riders of express services were more likely to use park and ride to reach transit than those of other types of services; local bus riders were more likely to walk to bus stops than other types of services, whereas access mode choice of LRT riders tended to be balanced. We also found that about 75% of riders walked farther than 0.25 miles to reach LRT stations (a critical value of walking distance widely considered by transportation planners) and the median is 0.37 miles.

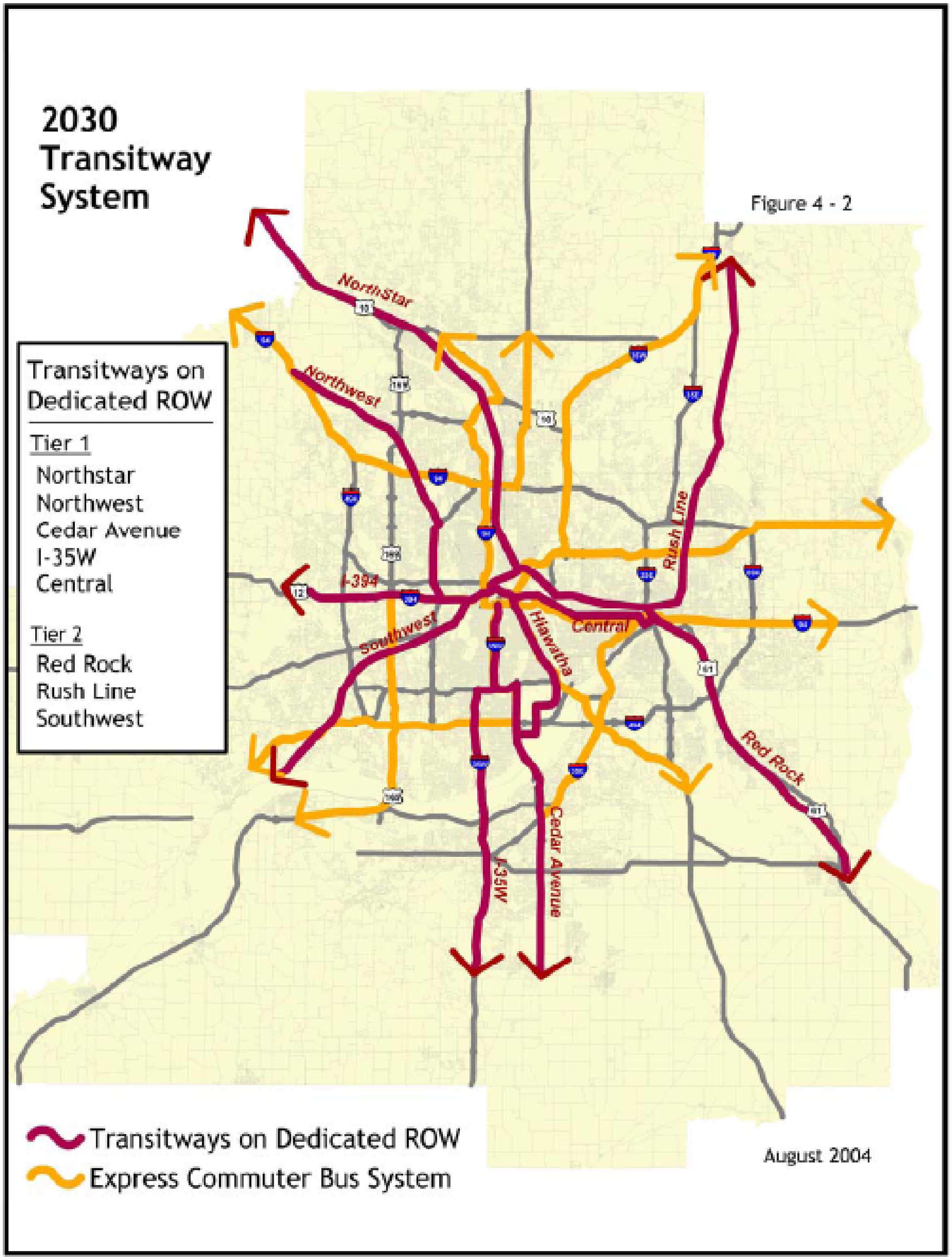
Multinomial Logit models for access mode choice of the Hiawatha LRT confirmed that riders' demographics, trip characteristics, built environment elements and social environment factors around LRT stations affect their access modes. Among these groups of variables, the distance from trip origin to LRT stations is the dominant factor that influences mode choice. We also found that the impacts of built environment elements on mode choice were equivalent to those of riders' demographics and trip characteristics, whereas the effects of social environment factors on mode choice were the weakest.

The mode choice analysis also provides some implications if we want to use the built environment to promote mode mixing. In particular, if the goal is to maximize the number accessing transitways from existing bus services, we should increase the coverage of feeder services, increase street connectivity and promote mixed-use development. If the goal is to attract choice riders in areas where walking and local transit are not options, more park and ride facilities should be provided.

1. INTRODUCTION

In the US, the goal of transportation planning has shifted from serving cars to serving people since the 1980s. Traditionally, federal and state governments rely on highway expansion to accommodate increasing travel demand. However, transportation finance can hardly catch up with the skyrocketing costs of highway construction. More importantly, many studies have contended that we cannot build our way out of congestion. According to the principles of demand and supply in Microeconomics, increasing supply will reduce prices of travel and hence unleash latent demand. Moreover, once additional highway capacity has eased congestion, people who changed their trip departure time, chose an alternative route, or used an alternative mode because of congestion are likely to switch back to their previous travel patterns, and soon the highway will be congested again – the iron law of congestion (Downs, 2004). Therefore, many large metropolitan areas have considered mass transportation as a viable way to address traffic congestion and its associate problems such as air pollution and climate change.

To cope with congestion and improve mobility, the Metropolitan Council of the Minneapolis-St. Paul (Twin Cities) metropolitan area has proposed a transit plan that will improve existing bus services and develop a network of dedicated transit corridors (Metropolitan Council, 2004). According to the 2030 Transportation Policy Plan, the final objective of this transit plan is to double the 2004 ridership by 2030. The short-term goal is to increase transit ridership by 50% in 16 years. Among this gain, twenty-two percent (or 8 million riders) will be achieved through the implementation of dedicated transitways including light rail transit (LRT), commuter rail, and bus rapid transit (BRT). Now the Hiawatha LRT is in full operation. Besides, several transitway programs are in process in the Twin Cities by March 2009: North Star commuter rail is under construction; Central Corridor LRT project has started preliminary engineering and is moving toward final design; and Northwest LRT, Southwest LRT, and Cedar Avenue BRT are in planning (Figure 1).



Source: Metropolitan Council (2004).

Figure 1. 2030 Transitway System in the Twin Cities

The transitways are major transportation investments by federal, state, and local agencies; the costs of the Hiawatha LRT were $715 million and $424 million were subsidized by federal governments (through the New Start program). Nationwide, the benefits and costs of rail transit are hotly debated. Many opponents criticized the popularity and expediency of rail transit in policy making. Charles (1998) summarized 10 myths about LRT based on the experience from Portland MAX; American Dream Coalition (undated, p.1) claimed that "With rare exceptions, rail transit is a costly and foolish investment that is more about pork barrel than it is about moving people". On the other hand, proponents of rail transit provide various types of evidence to counter these critics (e.g. http://www.lightrailnow.org/myths.htm).

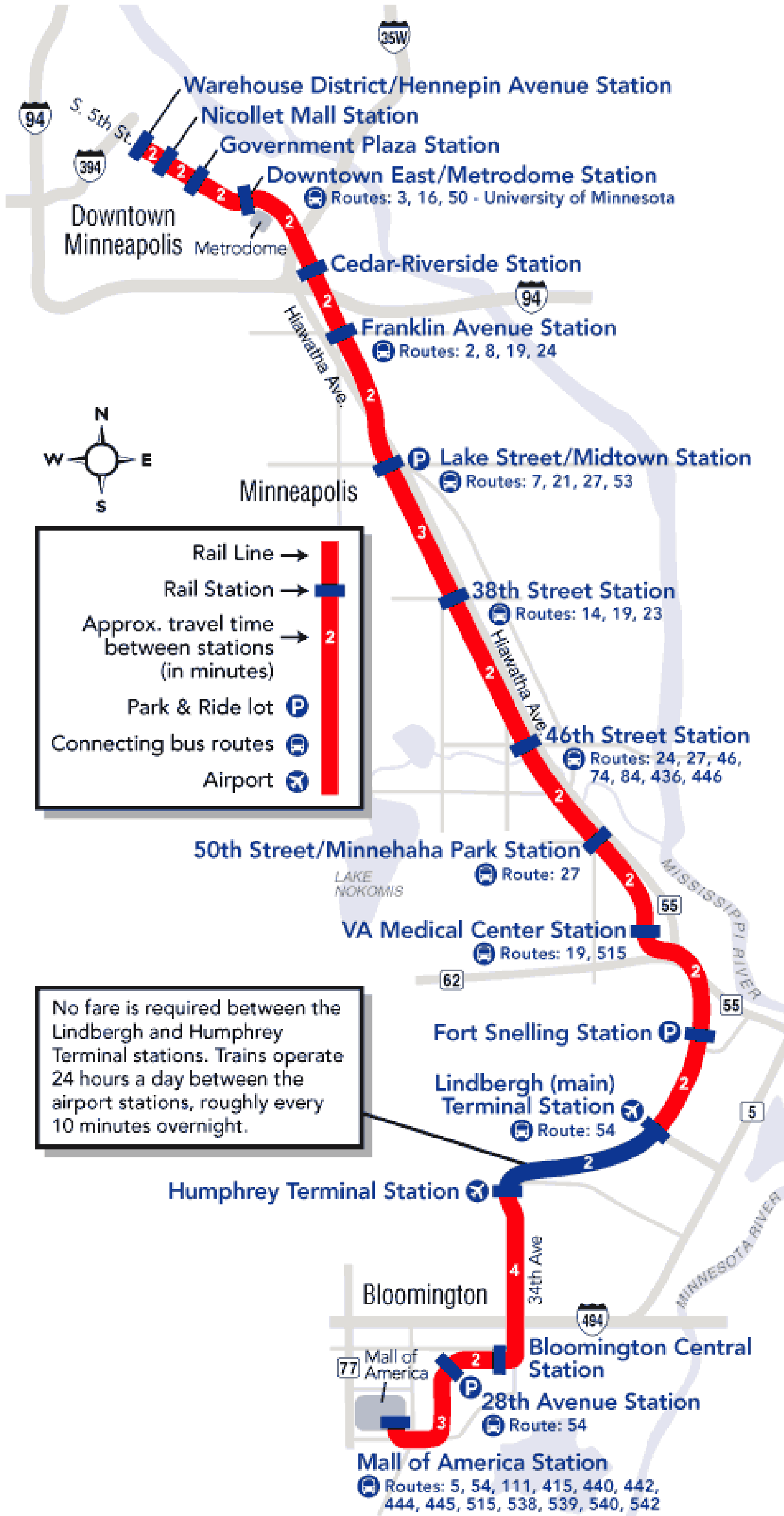
The Hiawatha line is the first LRT in Minnesota. A large number of public agencies (including Minnesota Department of Transportation, Metropolitan Council, metropolitan area counties and cities, Center for Transportation Studies, and Metropolitan Consortium) are involved in the development of transitways in the Twin Cities. Because there is no consensus regarding the impacts of transitways on transportation, it is imperative for legislators, planners, and the public to know whether transitways provide measurable transportation and economic benefits, the key to justify transitway investments. To manage the complexities surrounding the identification of important research questions, a group of local stakeholders (including representatives from the aforementioned agencies) have come together to form a Program Management Team (PMT) and Technical Advisory Group (TAG). These groups have identified a list of research questions related to transportation impacts of transitways.

The objectives of this study are to compare demographic differences of riders of light rail transit, express bus, premium express, and local bus service in the Twin Cities, and to investigate the factors that impact mode of access to LRT stations, using the 2005 data of Transit Rider Survey collected by Metropolitan Council. This research represents the first step in a long term effort to fully catalogue the transportation impacts of the transitway investments in the Twin Cities. The report is organized as follows: Section 2 will briefly introduce the Hiawatha LRT and the data used in this study; the next section presents the profile of transit riders in the Twin Cities; Section 4 focuses on mode of access to transitways; the last section replicates the key findings of this study.

2. HIAWATHA LRT AND DATA

The 12-mile Hiawatha LRT has 17 stations spanning from Minneapolis to Bloomington (Figure 2). Located on Minnesota State Highway 55, the Hiawatha LRT goes through residential neighborhoods in south Minneapolis and connects three large employment centers in the Twin Cities: downtown Minneapolis, Minneapolis-Saint Paul international airport, and the Mall of America in Bloomington. The Hiawatha LRT, operated by Metro Transit, fully opened in December 2004. In 2006, the ridership of the Hiawatha line reached 9.4 million, which exceeded the 2020 ridership forecast by about 14% (Metropolitan Council, 2007). To meet this high demand, Metro Transit expanded the light rail fleet from 24 to 27 cars. Currently, the LRT operates 21 hours a day from 4 am to 1 am. The headways range from 7.5 minutes during rush hours (6-9 am and 3-6:30 pm) to half an hour (late night and early morning). The one-way travel time from downtown Minneapolis to the Mall of America is 36 minutes.

The data used in this study came from the 2005 Metropolitan Council Transit Rider Survey (TRS). The survey was designed primarily to update the mode choice model in the regional travel demand forecasting model. The survey asked transit riders about the characteristics of their trips, including origin and destination, boarding and exit stations, access and egress mode choice, and trip transfer and purpose. The survey also contains a series of questions on sociodemographics. Given the culture diversity in the Twin Cities, the survey was developed in four languages: English, Hmong, Somali, and Spanish. Survey pretests were conducted on riders of a local bus route (16) and the LRT to improve the clarity of the survey and the adequacy of the logistics of data collection (SRF, 2006).



Source: http://metrotransit.org/rail/ (accessed on May 1, 2009).

Figure 2. Hiawatha LRT Map

To meet requirements of the forecast model, the sample was stratified on two dimensions: mode and time of day. The mode included local bus, express bus, commuter bus, and light rail. The time of day were classified into peak period and off-peak period. In late 2005 and early 2006, the survey was administered to 31,600 riders of all regular route services, bus, and LRT in the Twin Cities. The overwhelming majority of surveys were collected on board and others were collected by mail. The response rate was 90%. Of the completed surveys, 24,706 contained usable information, and 18,522 had valid origin-destination information. A preliminary examination of the data (SRF, 2006) showed that

- 63.9% of the riders use the bus or light rail five or more time per week;
- 63.1% of the trips are between home and work;
- The average rider uses 1.36 buses (or rail) per trip, with approximately 30.5% of trips making one or more transfers;
- The average age of a transit rider is 34.9 years, with 23.9% of riders between 25 and 34 years of age;
- 57.5% of riders are women;
- The average household income of a transit rider is $44,400 per year, but 22.7% of riders earn less than $15,000 per year;
- The average household has 1.21 vehicles, but 30.8% have no vehicles in their household, and 52.3% had no vehicle available to make the trip;
- 55.4% of the transit trips occur in either the AM or the PM peak periods.
- Detailed information regarding the data and survey methodology was presented in SRF (2006).

According to the number of access points, service frequency, and quality of vehicles, this study classified regular fixed-route transit services in the Twin Cities into four groups: local bus, LRT, express bus, and premium express. Local buses serve urban and suburban communities with frequent stops (e.g. Route 2). Local buses also include limited-stop services (e.g. Route 50). The LRT includes only the Hiawatha line. Express buses include express services that connect Minneapolis and St Paul downtowns (e.g. Route 94) and that connect suburban communities and one of the two downtowns (e.g. Route 355). Generally, express buses use regular buses like local routes, and some express routes use both regular buses and coach buses (Route 470). Premium express includes North Star commute coach (Route 888) and express buses with coach services. In 2005, Route 690 from Southwest Transit was the only express bus with coach services. Thus, premium express includes Routes 888 and 690.

In the Twin Cities, regular route services are operated by Metro Transit and several opt-out providers, including Minnesota Valley Transit Authority (MVTA), Southwest Metro Transit Commission (SMTC), Plymouth MetroLink, Maple Grove Transit, Shakopee Area Transit, and Prior Lake Laker Lines. North Star commute coach is operated by Anoka traveler.

3. PROFILE OF TRANSIT RIDERS

This chapter aims to answer the following central questions:

- Among local buses, LRT, express buses, and premium express, which mode has the highest percentages of choice riders?
- Do transit riders of different modes access transit stations/stops differently?
- Is transfer behavior different among transit users of different modes?
- Are there socio-demographic differences among transit riders of different modes?
- Do travel sheds of different transit modes differ?

3.1 Transitways and Choice Riders

Choice riders and captive riders are often used to distinguish transit riders in transit use analysis. According to the American Public Transportation Association (2006), transit captive means "a person who does not have a private vehicle available or cannot drive (for any reason) and who must use transit to make the desired trip", while a choice rider denotes a person whose travel choice set contains two or more motorized modes of transport. Transit captive is different from transportation- disadvantaged people, who usually have limited choice of travel modes. Besides captives, transportation-disadvantaged people also include the low-income, the elderly, and the handicapped. In this study, transit captive riders are defined as those who do not have a driver's license and do not have vehicles in the household. This definition is consistent with other studies (e.g., Polzin et al., 2000).

Among local bus, express bus, premium express, and LRT, which mode has the highest percentage of choice riders? Cross-tabulation chi-square test showed that transit modes and captive status of transit riders are dependent. Analysis of Variance (ANOVA) and post-hoc Bonferroni tests were then applied to disentangle which mode is different from other modes. As shown in Table 1, more than one third of local bus riders did not have a driver's license; but almost all premium express riders had a driver's license; eighty percent of LRT riders had a driver's license, ranking third. Vehicle ownership level showed a similar pattern: premium express riders had the highest level of auto ownership, followed sequentially by express bus riders, LRT riders, and local bus riders. Given that transit captives are those without a driver's license or a car, it is not surprising that premium express had the highest percentage of choice riders (96%), followed by express bus (84%) and LRT (69%). Note that all differences in these percentages between transit modes are statistically significant at the 0.05 level.

In the Twin Cities, all premium expresses and almost all express buses connect suburban communities (exurban, outer-ring suburban, and inner-ring suburban) and one of the two downtowns; only a couple of lines connect the two downtowns. There are disproportionate white-collar employments (e.g. professional, financial, insurance, and real estate) in the downtown area in the Twin Cities as well as in other large cities in the U.S. (Anderson and Bogart, 2001; Giuliano and Small, 1991). Residents who live in suburban communities and travel to the downtown tend to be affluent and have a high auto ownership (Table 1). Therefore, it is not surprising that express services are more likely to be taken by choice riders. On the other hand, express services have been criticized for its subsidy to affluent suburbanites and its contribution to suburban sprawl (Garrett and Taylor, 1999).

Table 1. Demographics and transfer behavior by transit mode

	Local Bus (LB)	Express Bus (EB)	Premium Express (PE)	Light Rail Transit (LRT)	p-value
% driver's license	64 [EB, PE, LRT]	88 [LB, PE, LRT]	98 [EB, LB, LRT]	80 [EB, PE, LB]	0.000
# vehicles	1.05 [EB, PE, LRT]	1.74 [LB, PE, LRT]	2.08 [EB, LB, LRT]	1.46 [EB, PE, LB]	0.000
% captive riders	52 [EB, PE, LRT]	16 [LB, PE, LRT]	4 [EB, LB, LRT]	31 [EB, PE, LB]	0.000
Household income	2.99 [EB, PE, LRT]	4.29 [LB, PE, LRT]	4.68 [EB, LB, LRT]	3.71 [EB, PE, LB]	0.000
Age	3.51 [EB, PE]	3.96 [LB, PE, LRT]	3.77 [EB, LB]	3.58 [EB]	0.000
% male	42 [EB, PE, LRT]	37 [LB, LRT]	35 [LB, LRT]	50 [EB, PE, LB]	0.000
Household size	2.76	2.71	2.81	2.73	0.078
Total routes used for the trip	1.62 [EB, PE, LRT]	1.30 [LB, PE, LRT]	1.16 [EB, LB, LRT]	1.56 [EB, PE, LB]	0.000

Notes:

a. The transit types in brackets indicate modes whose means are significantly different from the mean of this mode at the 0.05 level if not otherwise indicated. The Bonferroni method was used for this post-hoc test.

b. Income was measured using six indicators, with 1 denoting less tan $15,000, 2 denoting $15,000-$24,999, 3 denoting $25,000-$34,999, 4 denoting $35,000-$59,999, 5 denoting $60,000-$94,999, 6 denoting $95,000 or more. Age was measured using eight indicators, with 1 denoting under 18, 2 denoting 10-24, 3 denoting 25-34, 4 denoting 35-44, 5 denoting 45-54, 6 denoting 55-64, 7 denoting 65-74, and 8 denoting 75 and over.

The Hiawatha LRT balances choice riders (efficiency) and captive riders (equity). The LRT connects three major employment centers, going through residential neighborhoods. First, the LRT provides access to transit to those whose mobility depends on public transportation: 31% of LRT riders were captive riders. Second, the reliable and frequent LRT services enable reverse commute for those who lived close to the downtown area (or in north Minneapolis) and worked at Bloomington (such as the surrounding area of the Mall of America) or the south fringe of Minneapolis. Using ArcGIS 9.2, we examined residential and employment locations of LRT users. We found that 33% of workers commute outward from the central city. By contrast, very few riders used express services to conduct reverse commute, most likely because express services were infrequent or only served the direction of the peak-hour commute (as shown later in the travel sheds of Routes 355, 460, 690, and 888). Therefore, the Hiawatha LRT greatly increases job accessibility for low-skill workers, and has the potential to address the problems associated with spatial mismatch. Third, the LRT attracts urban and suburban choice riders through park and ride facilities and abundant bus-connection services. The LRT has three park and ride locations: Lake Street/Midtown Station, Fort Snelling Station, and 28th Avenue Station.

Among 3,497 LRT riders in this sample, about a third (1,153) have used park and ride mode (either solo-driving or carpooling) at one end of their trips. Most LRT stations are connected with local buses or express buses. Besides stations in the downtown area, Mall of America Station and 46th Street Station are major transfer stations. About 30% of LRT riders accessed the train through bus connection (Table 2).

Table 2. Access mode choice of LRT riders

Mode		Frequency	Percent
Walk		1291	36.9
Bike		20	0.57
Bus		1054	30.1
Park and Ride	Drive and ride with someone and park our vehicle	221	6.32
	Drive by myself and park my vehicle	661	18.9
Park and Kiss	Drop off or pick up	179	5.12
Other		67	1.92
Missing		4	0.11
Total		3497	100

3.2 Mode-Mixing of Transitways

The Hiawatha LRT promotes mixing of multiple modals. First, the modes used to access LRT stations were balanced. As shown in Table 2, 37.5% of LRT users adopt non-motorized modes (the vast majority is pedestrian access); 30.1% rode buses to access LRT stations; 30.3% adopted driving-related modes (either park and ride or drop off/pick up). However, riders of express routes and (especially) premium expresses were much more likely to use driving-related modes to access stations than LRT users (Table 3). The majority of the increases in driving-related mode share are attributable to park and ride of solo-drivers.

Table 3. Percentage of driving-related modes in access mode choice

Mode		Local Bus	LRT	Express Bus	Premium Express
Park and Ride	Carpooling	1.6	6.3	4.8	8.6
	Solo-driving	5.2	18.9	33.6	45.9
Kiss and ride	Drop off or pick up	2.8	5.1	4.5	7.9
Total		9.6	30.3	42.9	62.4

Second, LRT users were more likely to make a transfer to other types of transit than riders of express services. Overall, local bus riders were the most likely to make transfers: on average, local bus riders made 0.62 (= 1.62 - 1) transfers to reach their final destinations (Table 1). Premium express riders were the least likely to make a transfer to other transit (0.16). That is, most premium express riders worked or stopped at the areas within walking distance of non-home-end stations. LRT riders also tended to make transfers. Although the numbers of transfers between local buses and LRT riders are statistically significant at the 0.05 level, the magnitude of transfers of LRT riders is much closer to that of transfers of local bus riders. In other words, like local buses, the LRT greatly encourages the mixing of different transit modes.

3.3 Travel Sheds of Different Transit Modes

The Hiawatha LRT tends to facilitate mode-mixing: people access to LRT stations almost equally by car, bus, and non-motorized modes. Therefore, it is expected that Hiawatha LRT users share some characteristics with both local bus riders and express bus riders. On the one hand, the LRT improves the accessibility of the Hiawatha corridor and hence attracts local riders. On the other hand, LRT stations are multi-modal transit centers and hence the LRT attracts riders from the whole region.

To illustrate the influence of the Hiawatha LRT on regional accessibility, we compared travel sheds of different types of transit. Here, a transit travel shed is a GIS plot of the residential locations of users of a particular transit route. Visually, the larger a travel shed is, the larger the influence of a transit on regional accessibility is. To enumerate the spread of a travel shed, we chose a couple of quantitative measurements as follows:

$$SD = \sqrt{\frac{\sum (d_i - \bar{d})^2}{n-1}}\ ,\ ,\ RMSD = \sqrt{\frac{\sum d_i^{\ 2}}{n}}$$

where d_i is the Euclidean distance from Rider *i*'s home to a transit route; $\bar{d}$ is the mean Euclidean distance for riders of the route; n is the number of riders observed on the route; SD and RMSD are the respective standard deviation and root mean square of the Euclidean distance. Generally, large SDs and RMSDs indicate a large influence of the transit on regional accessibility.

Routes 4 and 5 are two local buses almost parallel to the Hiawatha LRT. Route 4 connects New Brighten and 82nd street transit center, going through downtown Minneapolis; Route 5 serves Brooklyn Center and Mall of America, also going through downtown Minneapolis. According to Figures 3 and 4, the vast majority of riders on Routes 4 and 5 lived very close to transit routes, although the two routes also served some riders from a large region. Overall, local buses mainly serve narrow corridors along bus routes. In contrast, the travel shed of the Hiawatha LRT is much broader than that of a local bus. Most LRT riders were from Hennepin County; many lived in Dakota and Ramsey Counties; some were from Anoka, Washington, and Scott Counties. Empirically, on average, LRT riders lived about 3.5 miles away from the route, which are 2.5~3.5 times farther than the mean distances between homes of local bus riders and local routes (Table 4). The spread of the LRT travel shed is about 2.5 times broader than that of the travel shed of a local bus. Therefore, the LRT not only improves the accessibility along the Hiawatha corridor, but also plays an important role in enhancing regional accessibility.

The mean distances between homes and transit routes were similar for riders of the LRT, Route 460 (Burnsville – University of Minnesota), Route 355 (Woodbury – Downtown Minneapolis), and Route 690 (Eden Prairie – Downtown Minneapolis). However, the spread of the LRT travel shed was larger. Further, the vast majority of riders on Routes 460, 355, and 690 were from suburban communities they served (Figures 6, 7, and 8). Therefore, although express services can serve a large proportion of choice riders, its ability to improving regional accessibility is rather limited.

Table 4. Characteristics of travel sheds

Routes	Mean Distance	Standard Deviation	Root Mean Square Distance
LRT	3.48	7.89	8.62
4	0.77	2.44	2.56
5	0.98	2.15	2.36
460	4.09	6.77	7.90
355	3.25	5.20	6.12
690	3.17	5.22	6.19
888	7.30	8.03	10.83
16	1.91	3.19	3.72
50	4.11	5.64	6.97
94	3.23	4.83	5.81

Route 888 served riders from a large area and its mean distance and spread exceeded those of the Hiawatha LRT (Table 4). All riders were exclusively from the Big Lake area, and similarly, its ability to enhancing regional accessibility is limited (Figure 9). However, this observation is not surprising since the suburban end of Route 888 is mainly bedroom communities. Travel shed may change over time once North Star Commuter Rail is open and transit-oriented developments are booming in those communities.

The proposed Central Corridor LRT will connect Downtown Minneapolis and Downtown St. Paul via the University Avenue. Currently, these two downtowns are connected by Routes 50 (a limited-stop local bus), 16 (a local bus), and 94 (an express bus). Central Corridor will replace Route 50; headways of Route 16 will increase accordingly; and Route 94 will remain unchanged. Previous research has shown that compared to bus riders, LRT riders would be willing to walk a longer distance to reach LRT stations. Therefore, it is expected that all riders of Route 50 and most riders of Route 16 will be absorbed by Central Corridor. Further, some riders of Route 94 may switch to Central Corridor. Thus, the overlay of travel sheds of Routes 16, 50, and 94 may illustrate a coarse travel shed of Central Corridor. As shown in Figure 10, the overlay of travel sheds tends to be regional. Once park and ride facilities and bus feeder services are provided, Central Corridor is likely to serve more riders from Ramsey, Dakota, and Washington Counties. Overall, similar to the Hiawatha LRT, the influence of Central Corridor on accessibility enhance tends to be regional.

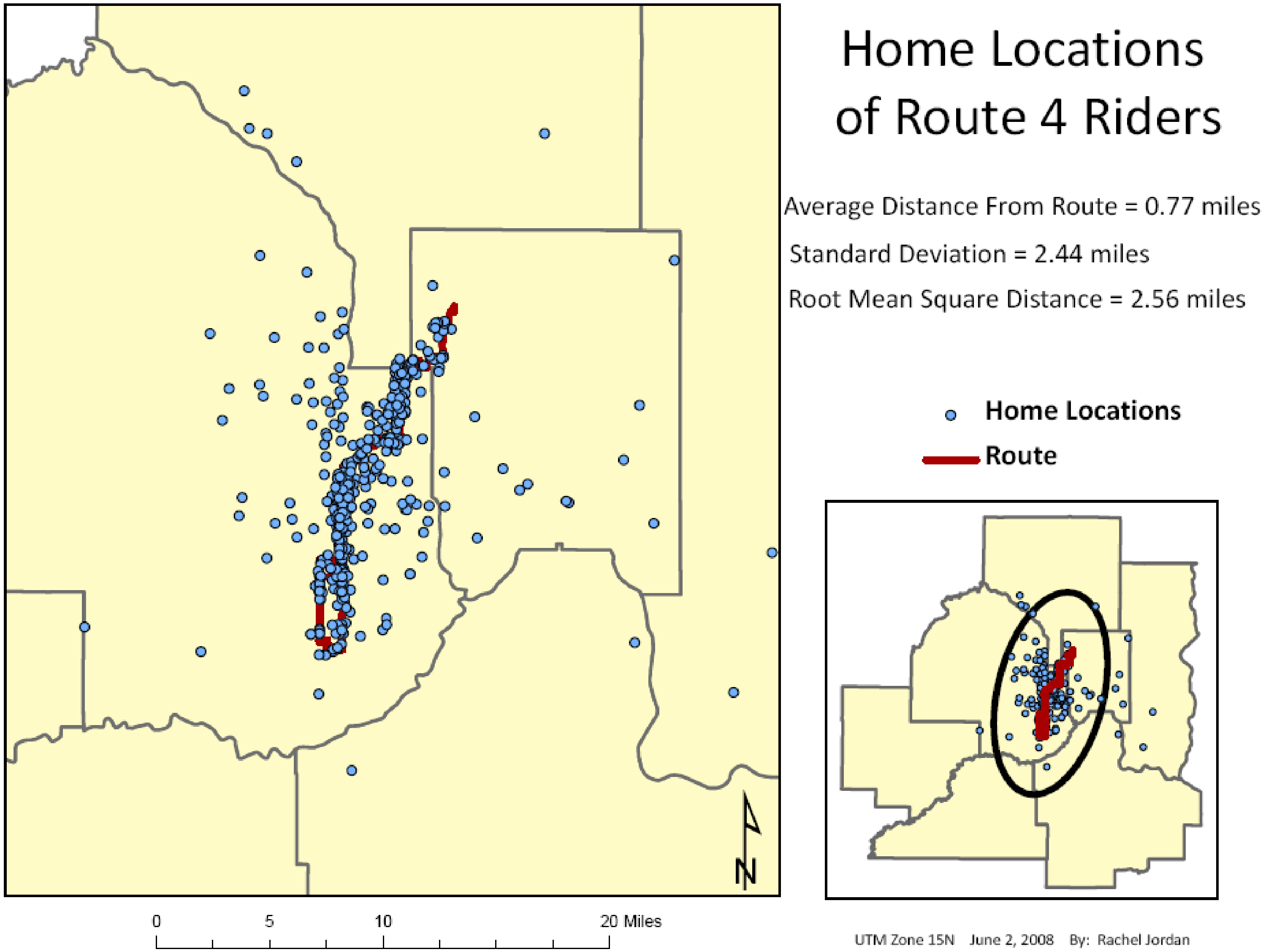


Figure 3. Travel Shed of Route 4 (Local Bus)

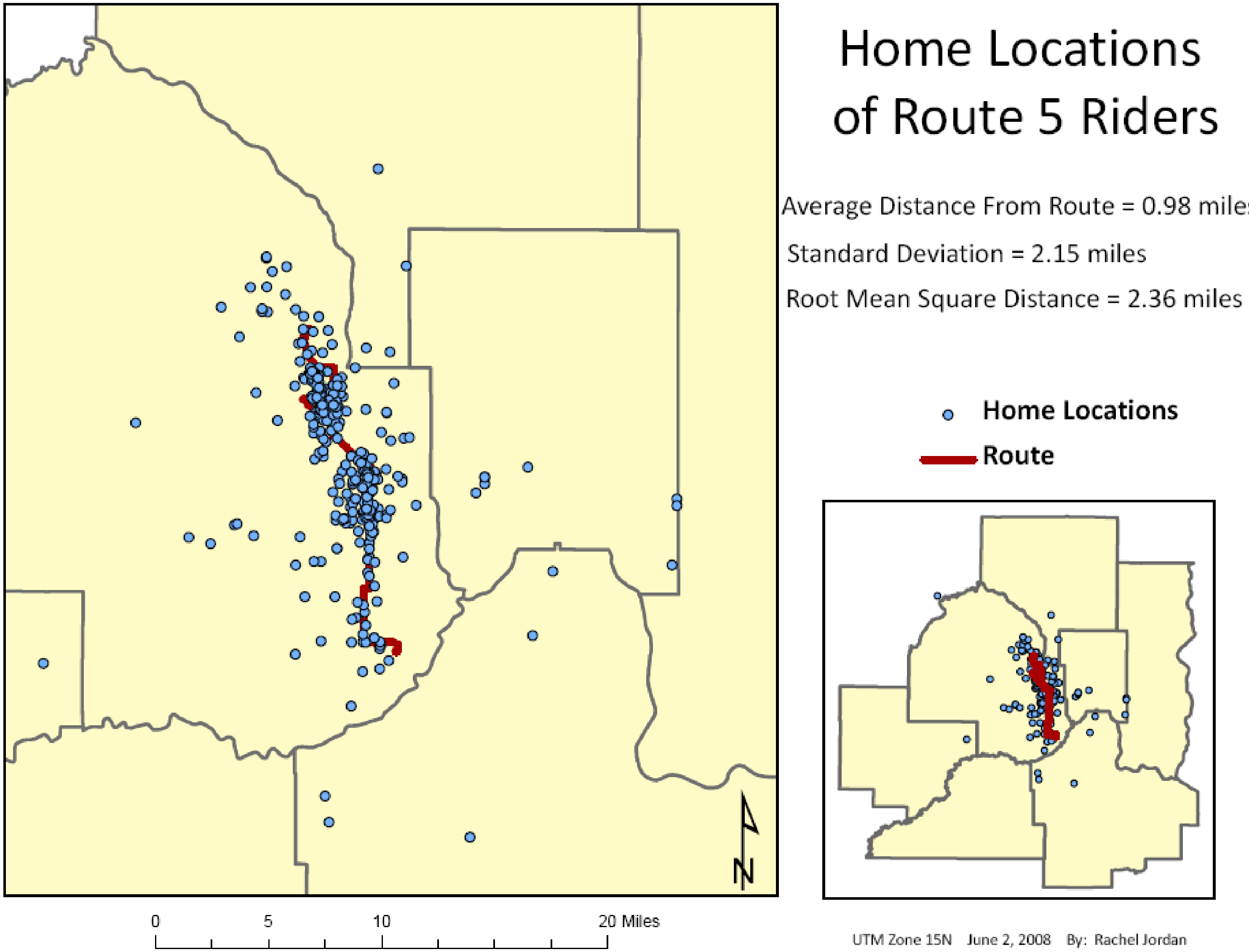


Figure 4. Travel Shed of Route 5 (Local Bus)

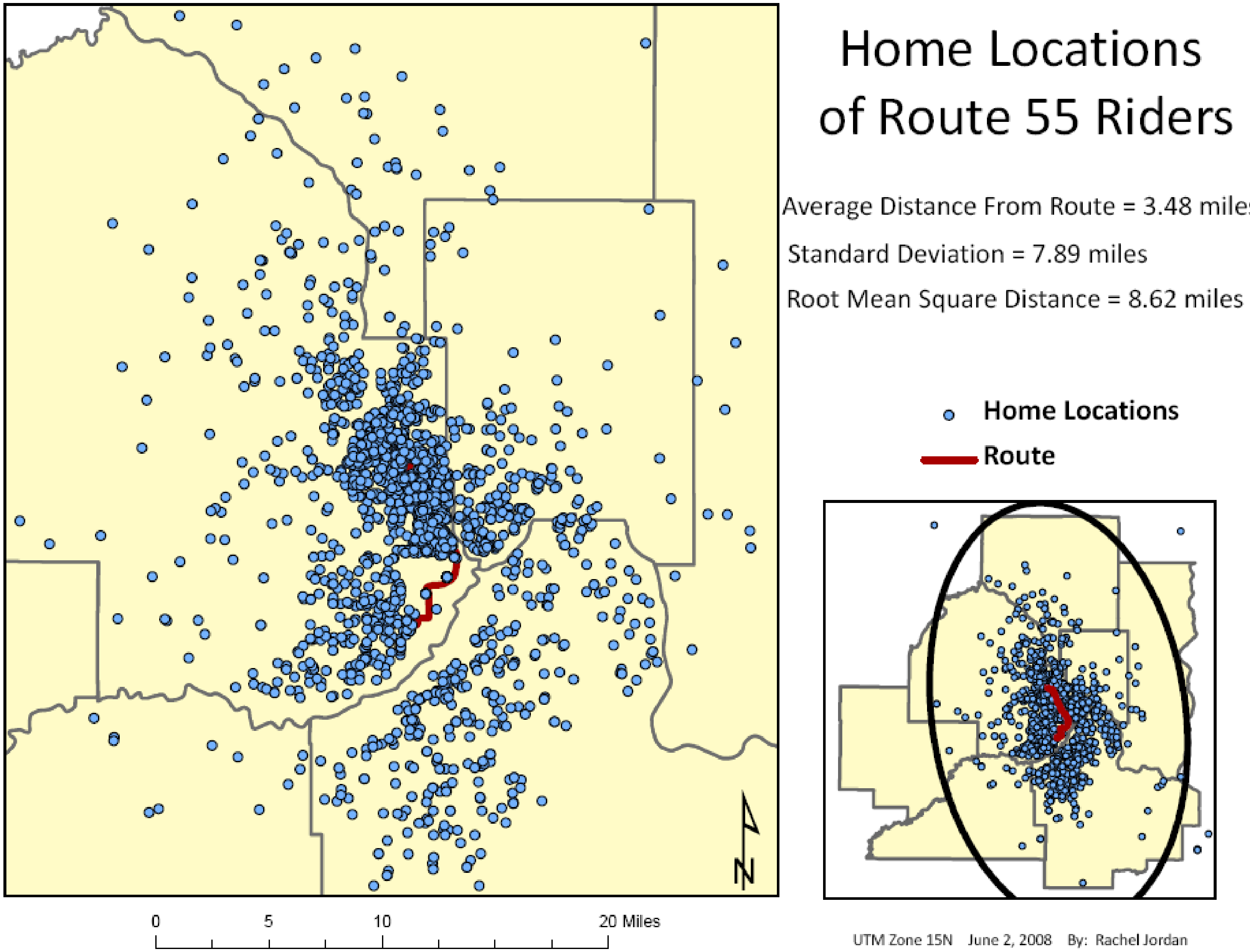


Figure 5. Travel Shed of Hiawatha LRT

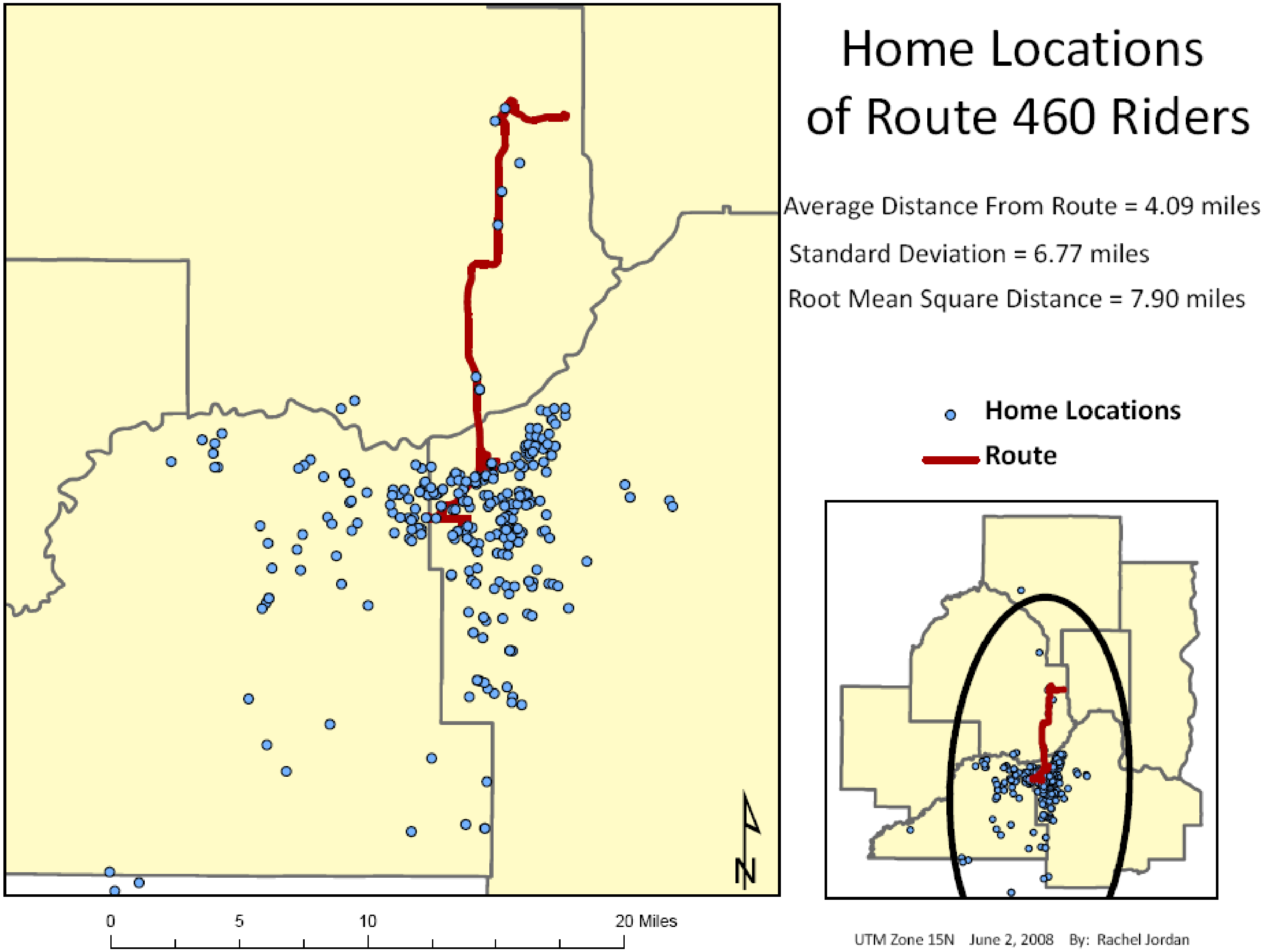


Figure 6. Travel Shed of Route 460 (Express Bus)

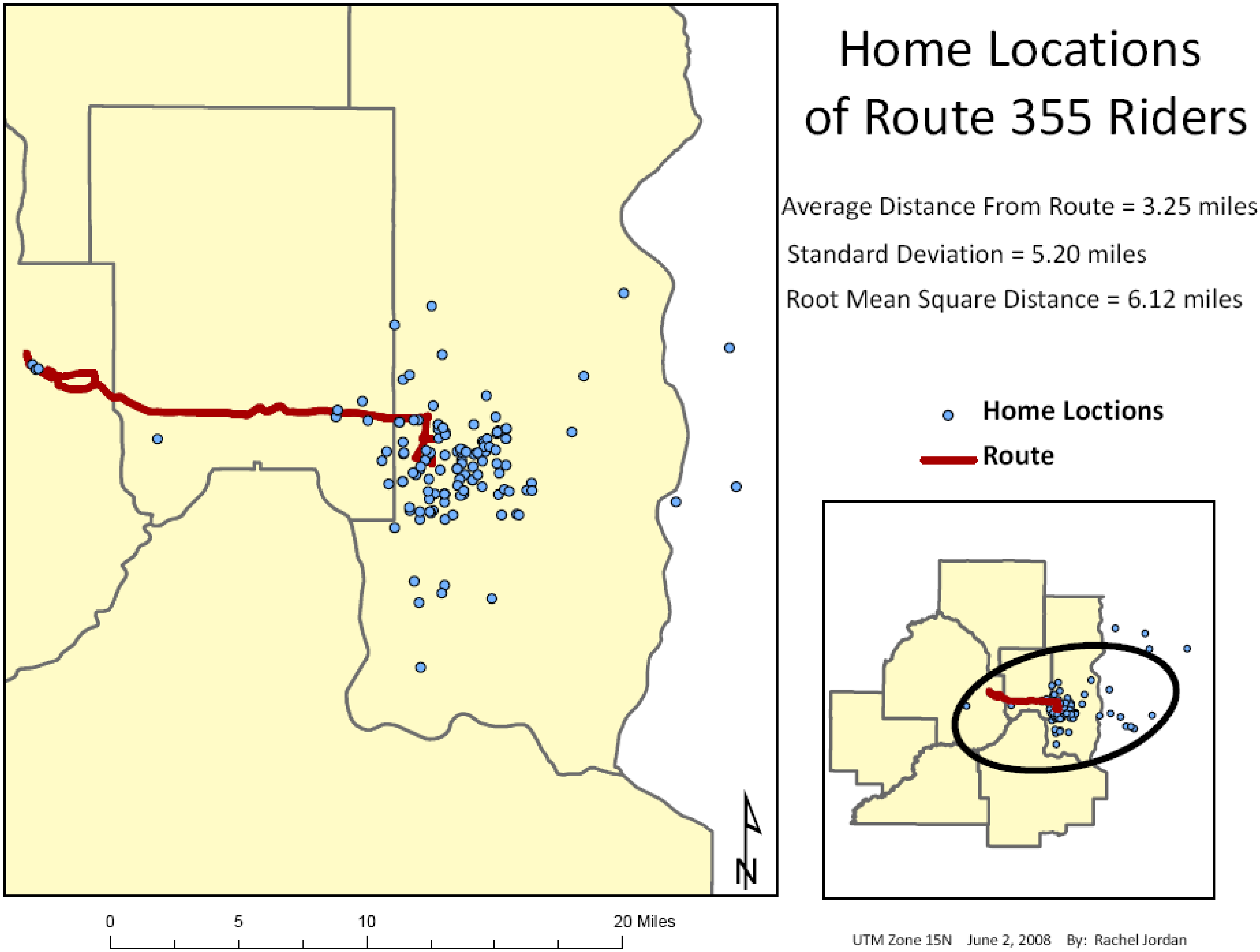


Figure 7. Travel Shed of Route 355 (Express Bus)

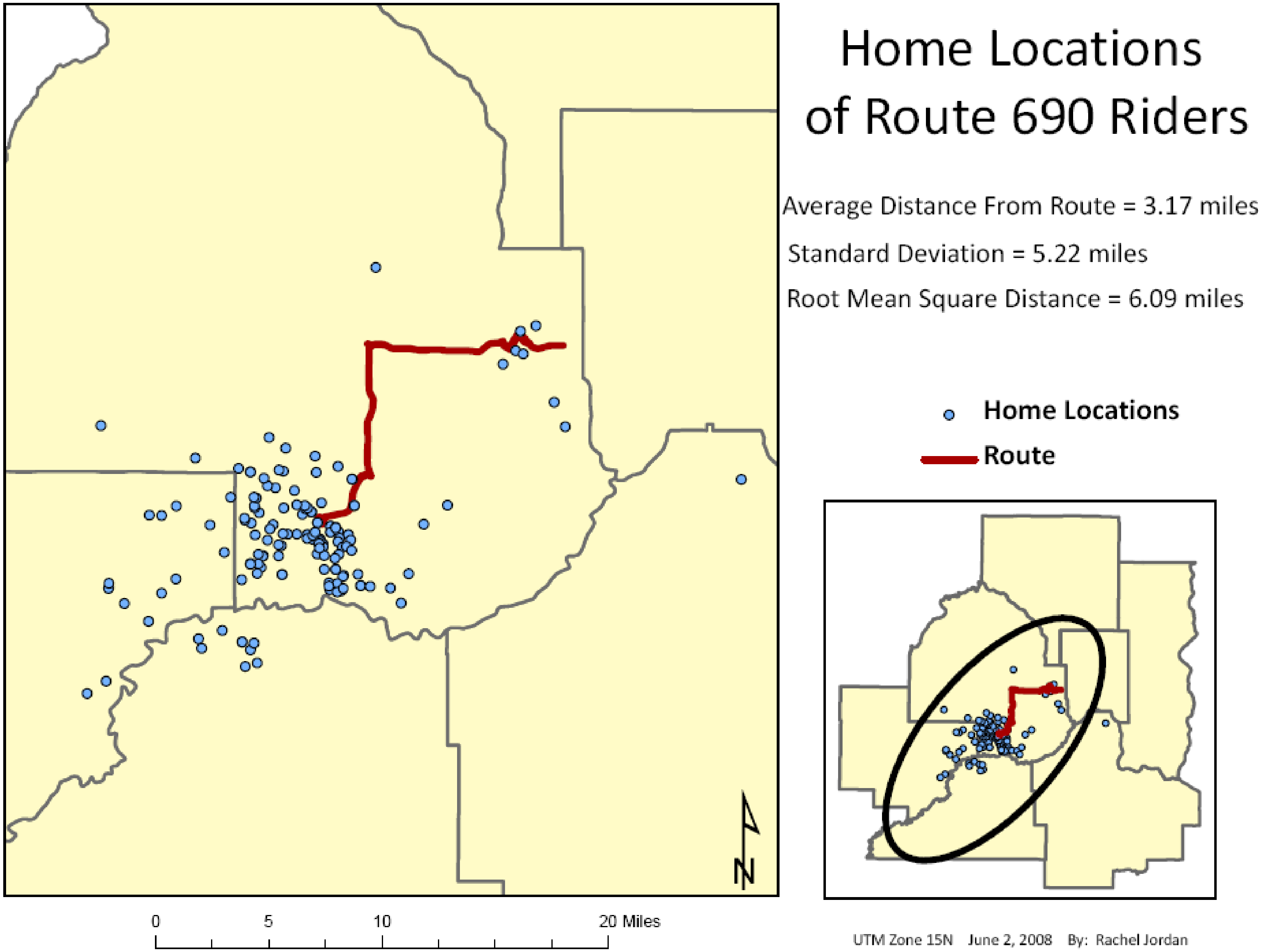


Figure 8. Travel Shed of Route 690 (Premium Express)

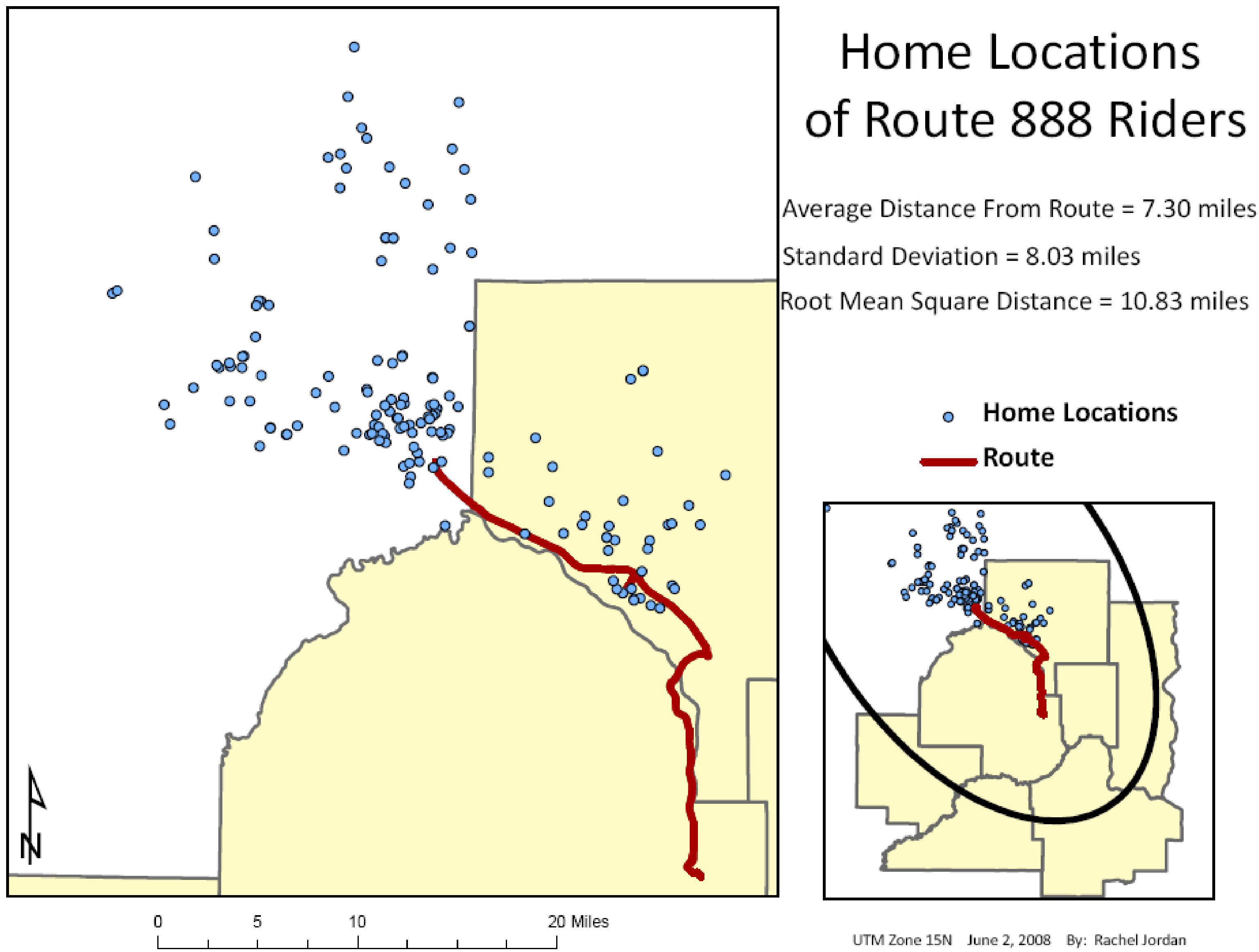


Figure 9. Travel Shed of Route 888 (Premium Express)

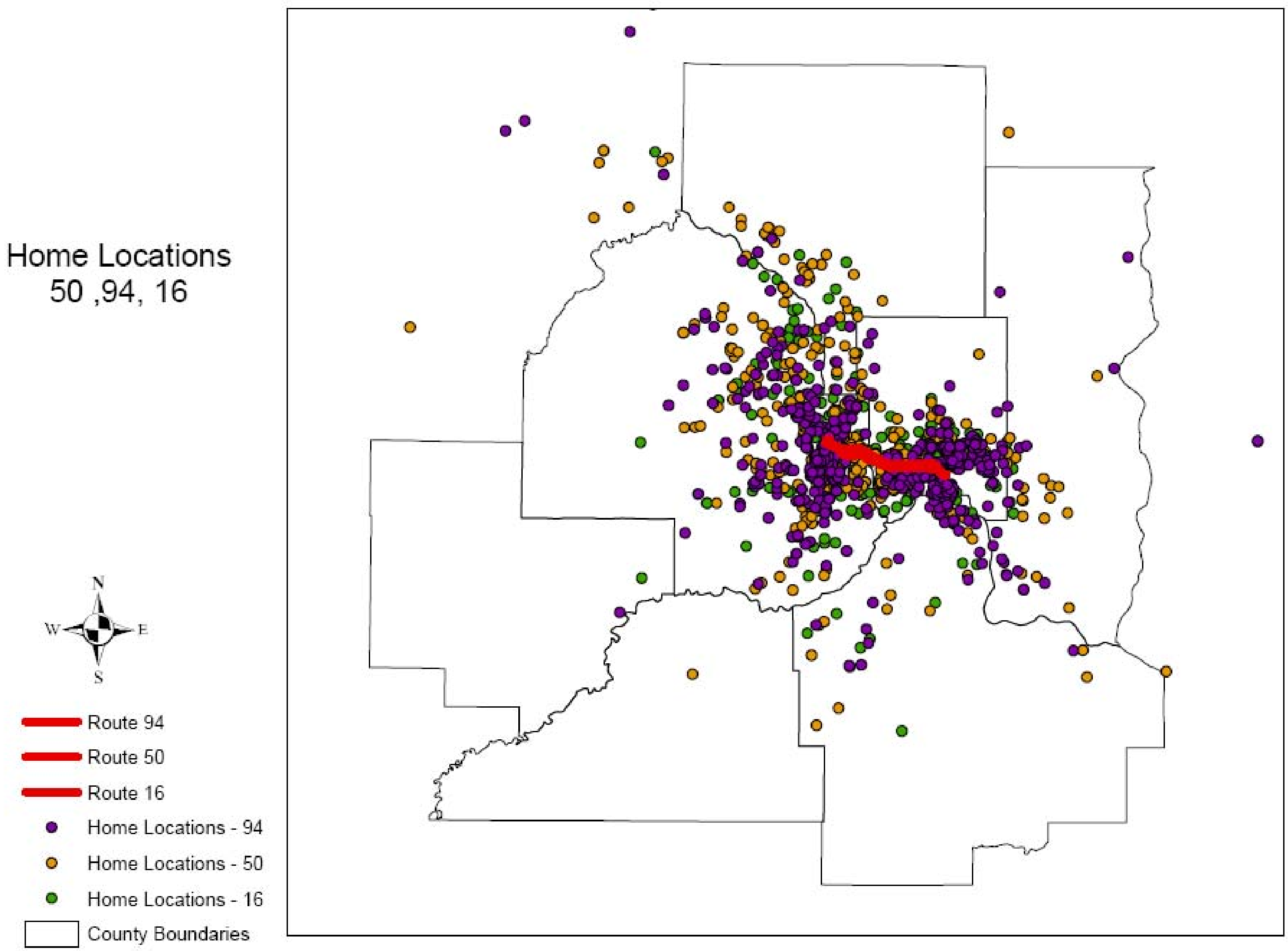


Figure 10. Travel Shed of Routes 16, 50 and 94

3.4 Other Characteristics of Transit Users

Household income follows the same pattern as vehicle ownership; premium express users tended to be the most affluent, followed by express bus users, LRT users, and local bus users (Table 1 and Figure 11). In the sample, the majority (58%) of riders were women. For different types of services, express services had the lowest percentages (35% and 37%) of male riders and the LRT served the highest percentage (50%) of male riders. This disproportionate share of male users on LRT suggests that men tend to take LRT although in general they are less likely to take transit than women. On average, express bus riders tended to be the eldest, followed by premium bus riders, LRT riders, and local bus riders.

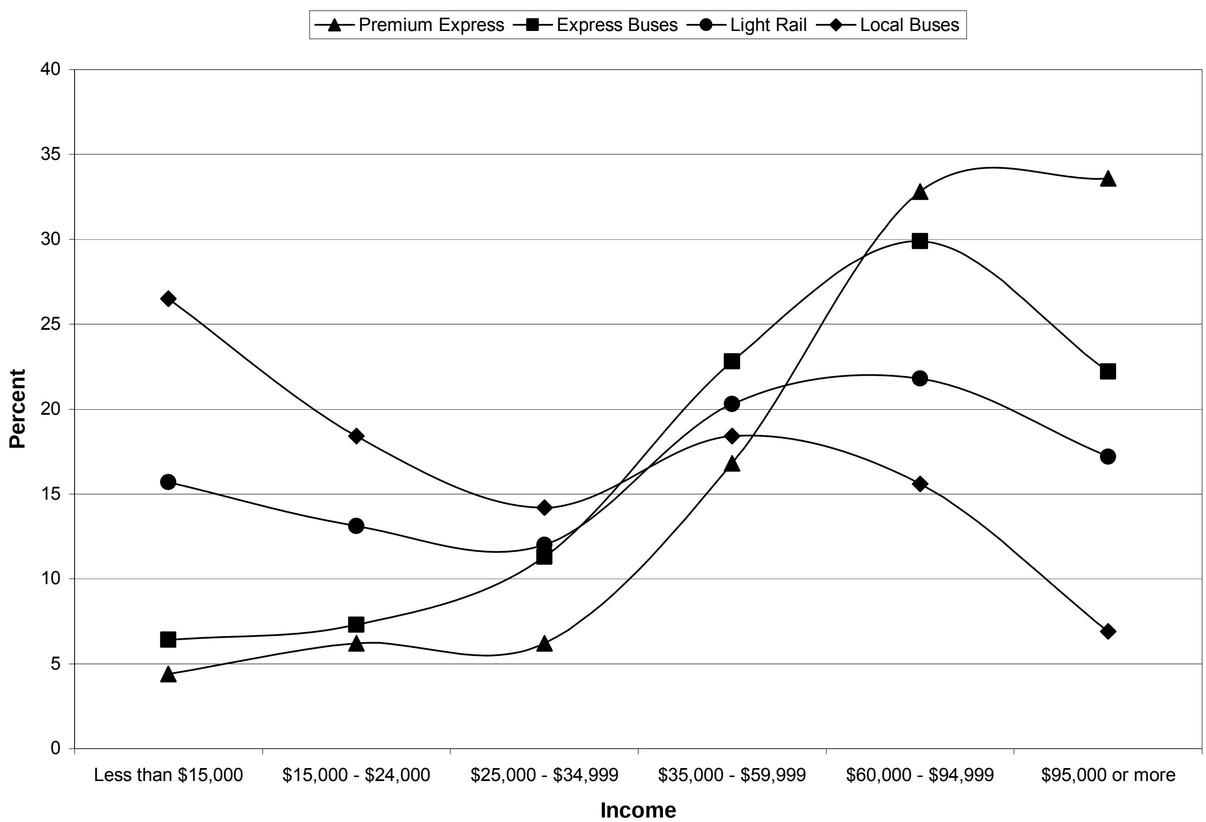


Figure 11. Income Distribution of Transit Users

Characteristics of transit riders also differ in geography of transit routes (Table 5). For local bus users, suburban route riders tended to be choice riders, younger, have a higher auto ownership, have a driver's license, and have a higher household income than urban route riders. For express bus users, urban-urban route riders were more likely to be captive riders, poor, male, live in a small household, have a low auto ownership, and fewer with a driver's license than suburban-urban route riders.

Table 5. Geographical differences of transit users

	Local	Route		Express	Route	
	Within urban	Within suburban	p-value	Urban-urban	Suburban-urban	p-value
% driver's license	63	67	0.001	76	90	0.000
# vehicles	1.02	1.30	0.000	1.15	1.81	0.000
% captive riders	53	43	0.000	37	13	0.000
Household income	2.92	3.49	0.000	3.71	4.36	0.000
Age	3.83	3.47	0.000	3.92	3.97	0.293
% male	43	40	0.120	45	36	0.000
Household size	2.76	2.79	0.569	2.48	2.74	0.000

Note: Income was measured using six indicators, with 1 denoting less tan $15,000, 2 denoting $15,000-$24,999, 3 denoting $25,000-$34,999, 4 denoting $35,000-$59,999, 5 denoting $60,000-$94,999, 6 denoting $95,000 or more. Age was measured using eight indicators, with 1 denoting under 18, 2 denoting 10-24, 3 denoting 25-34, 4 denoting 35-44, 5 denoting 45-54, 6 denoting 55-64, 7 denoting 65-74, and 8 denoting 75 and over.

4. MODE CHOICE OF ACCESS TO TRANSITWAY STATIONS

The 2030 Transportation Policy Plan aims to double the 2004 transit ridership level in the Twin Cities area by 2030. To achieve this goal, one strategy is to develop a regional network of transitways. The transitways would have travel advantages - dedicated rights of way (including shoulder bus lanes and exclusive bus lanes), ramp meter bypass, and intelligent-transportation system enhancements – with the goal being comparable to or superior to driving in terms of travel time.

If we build it, will people come? This question points to the importance of understanding the factors that affect individuals' choice of transit. A transit trip constitutes at least three components: access trip to stations (or stops), primary transit trip, and egress trip from stations (or stops). Previous studies mainly explored influential factors of primary mode of a transit trip, because mode choice models often deal with only the primary mode of a trip. It was found that on-board travel time is an important determinant of transit choice (Koppelman and Bhat, 2006). We believe that transitways have a larger potential to serve choice riders than regular services because of shorter on-board travel time. However, access and egress trips are also important for transit choice because any barriers to the three components are likely to deter individuals' choice of transit. For example, poor pedestrian access to transit stations is likely to discourage local riders. Therefore, it is imperative to understand the factors that influence individuals' access trips so that we can remove any potential barriers. Table 6 presents some factors that have the potential to influence mode choice. Further, providing a multi-modal transit system is the key to achieving the ridership goal. Transitway stations are "focal points of multimodalism intended to increase ridership" (Kim et al., 2007, p.513). Therefore, the environment of these stations is critical to establishing a multi-modal transitway system.

4.1 Mode Classification of Access to the Hiawatha LRT

In the survey, respondents were asked to indicate how they got to the first bus or train they rode on the trip. Six options were provided, including "walked", "rode bicycle", "drove by myself and parked my vehicle", "drove or rode with someone and parked our vehicle", "dropped off by someone", and "other". Note that the bus access was not available in the choice set since the question explicitly asked the access of the first bus (if a rider walks to a bus stop and then takes a bus to a LRT station, her answer is walk although her access to the LRT station is bus). Based on transfer-related questions in the survey, we identified bus access to LRT stations and reclassified mode of access to LRT stations into seven categories as shown in Table 7. Overall, there were 3,497 respondents riding the LRT when the survey was taken. Among them, 21 riders biked to LRT stations, and 7 used other modes. Because of limited observations, riders who used these two modes were removed from further analysis. In addition, those who drove or rode with someone and parked, and those who drove alone and parked are virtually "park and ride" users; they were combined as a single category. Therefore, riders accessed LRT stations by one of the four different modes: bus, walk, park and ride, and kiss and ride (pick up/drop off).

Table 6. Factors assumed to affect mode choice of access trips

Riders' demographic characteristics
Auto ownership; Driver's license; Income; Gender; Age; Household size
Trip characteristics
Peak or nonpeak; AM or PM; Work or non-work
Distance from trip origin to transit stops/stations
Network distance from home to light rail stations
Built environment characteristics of stations
Land use patterns: density, land use mix, accessibility, etc.
Transportation systems: parking availability and policy, feeder service, sidewalks, and bikeways
Social characteristics of surrounding neighborhoods of stations
Income level; Ethnicity; Housing types…

Table 7. Frequency of access mode to LRT

		Frequency	Percent
Valid	Took a bus	1077	30.8
	Walked	1326	37.9
	Drove or rode with someone and parked	221	6.3
	Biked	21	0.6
	Dropped off	179	5.1
	Drove alone and parked	662	18.9
	Other	7	0.2
	Total	3493	99.9
Missing	System	4	0.1
Total		3497	100

4.2 Distance Decay of Access Trips

Generally, transportation planners assume that bus riders are likely to walk a quarter mile to reach bus stops and LRT riders are willing to walk half a mile to access LRT stations. For example, O'Sullivan and Morrall (1996) found that on average, LRT riders walk 0.4 miles to reach stations; Cervero (2001) found that for access trips shorter than 5/8 miles, walking dominates access mode choice. Do our data follow this common understanding? To answer this question, we applied the network distance function of ArcGIS to calculate the network distance from trip origins to LRT stations. Among 1,326 riders who walked to LRT stations, 239 cannot be geo-coded because they do not have complete origin or destination information. Further, many riders who reported walking to LRT stations actually did not walk to the stations because they would not walk miles to reach the stations

For the 829 LRT riders who walked less than a mile (Table 8), the mean walking distance is 0.39 miles; the median walking distance is 0.37 miles and 75% of riders walked less than 0.56 miles to reach LRT stations. For the 916 riders who walked less than 2 miles, the mean walking distance is 0.48 miles (Figure 12); the median walking distance is 0.41 miles and 75% of riders walked less than 0.69 miles to reach LRT stations. Our results are roughly consistent with the literature: the majority of LRT riders have walked more than a quarter mile to reach the stations.

Table 8 also shows that on average, LRT users who parked and rode lived farthest from the stations, followed by riders who were dropped off, and riders who took a bus. These are also consistent with our expectations. The distribution of the distance from trip origins to LRT stations was illustrated in Figure 12. The origins of most LRT riders who transferred from a bus were within 2.5 miles of LRT stations. This result suggests that feeder services of the LRT should focus on this niche market. Most riders who were dropped off were also from locations within 2.5 miles of LRT stations, while park and ride users tended to live farther away from LRT stations.

Table 8. Distance to LRT stations by different modes

		Walk	Bus	Park and ride	Kiss and ride
N	Valid	829	881	596	132
	Missing	0	196	287	47
Mean		0.39	3.27	6.90	4.38
Std. Deviation		0.23	3.38	5.41	4.33
Percentiles	25	0.20	1.16	2.50	1.08
	50	0.37	2.03	5.86	2.41
	75	0.56	4.31	9.83	6.54

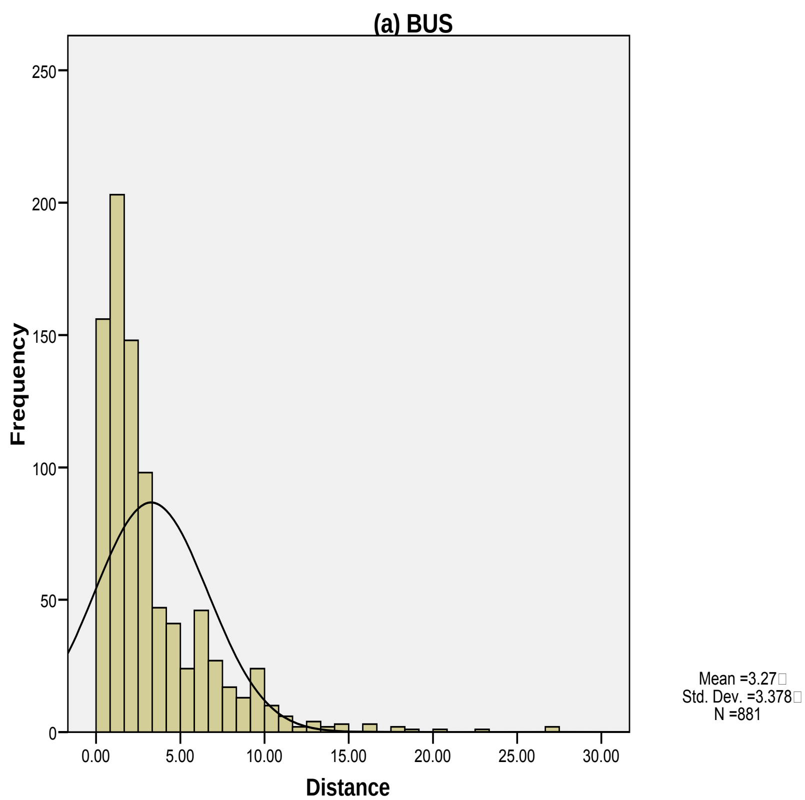
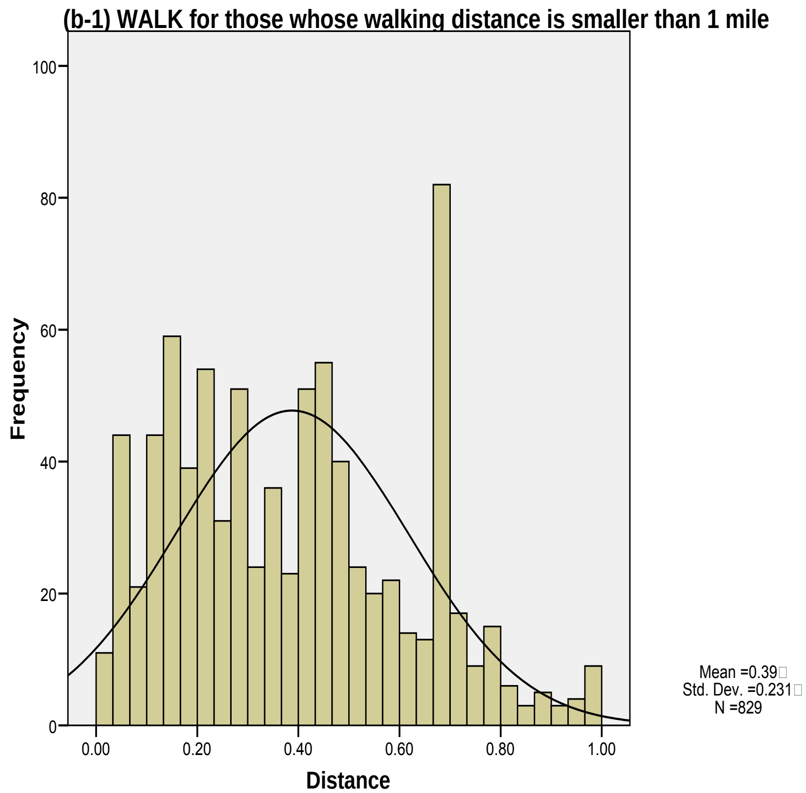


Figure 12. Distribution of Access Distance by Mode Choice



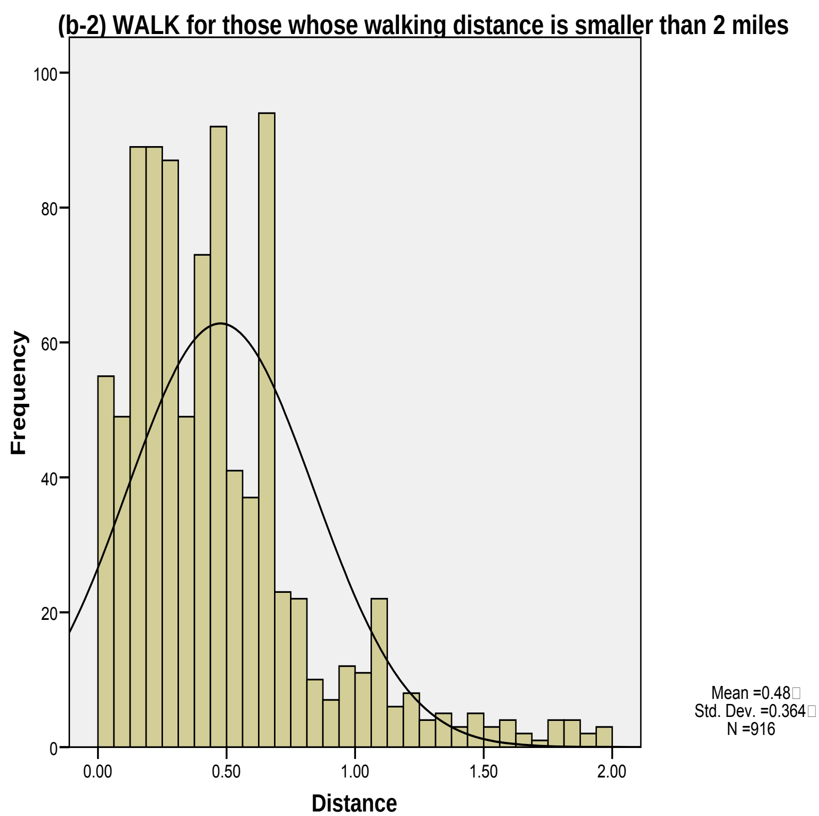
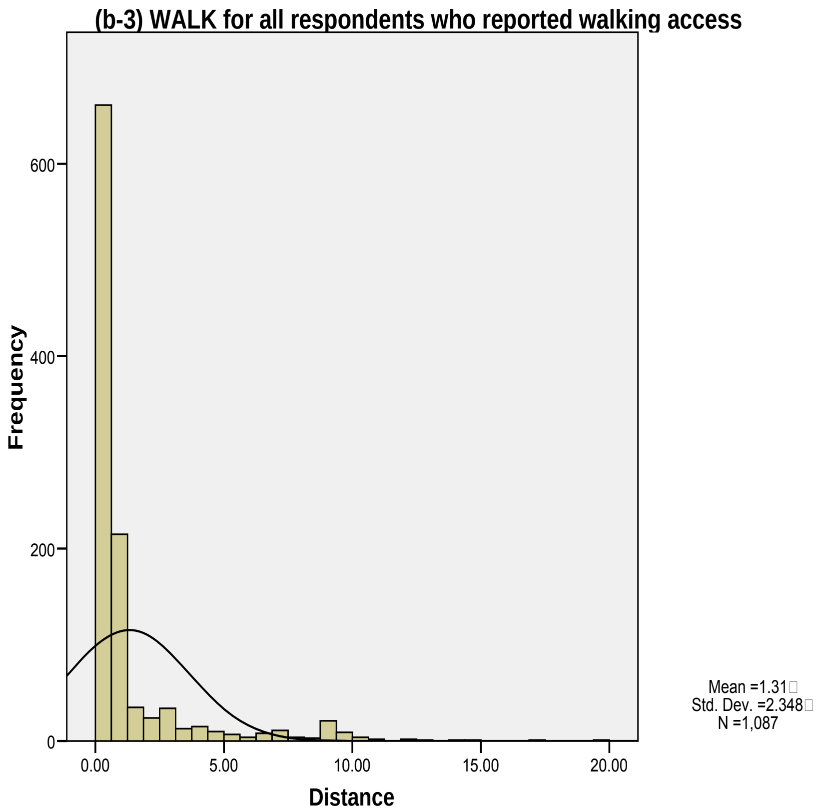


Figure 12. Distribution of Access Distance by Mode Choice (cont.)



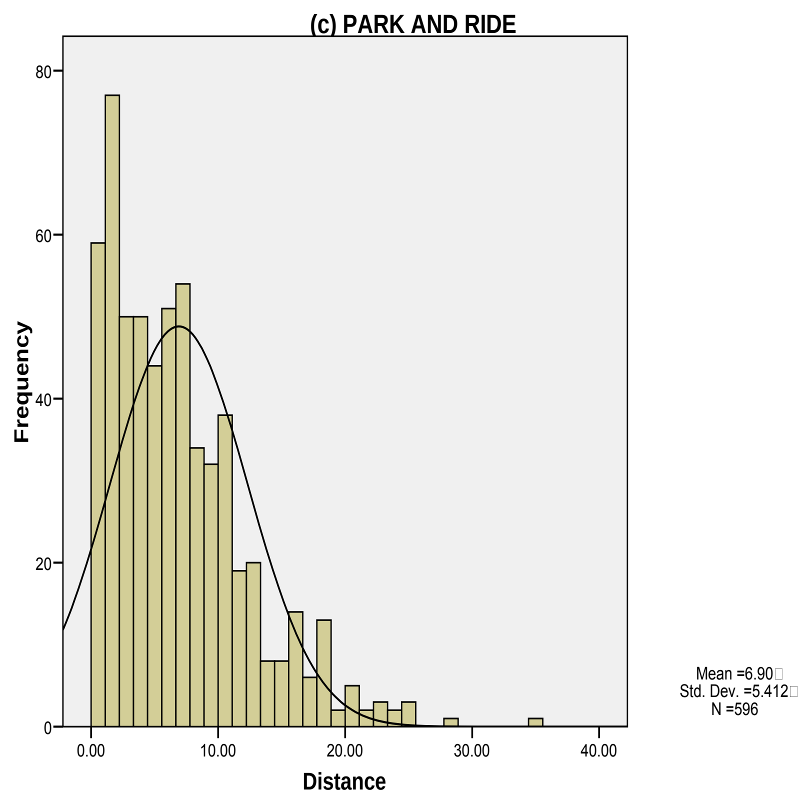


Figure 12. Distribution of Access Distance by Mode Choice (cont.)

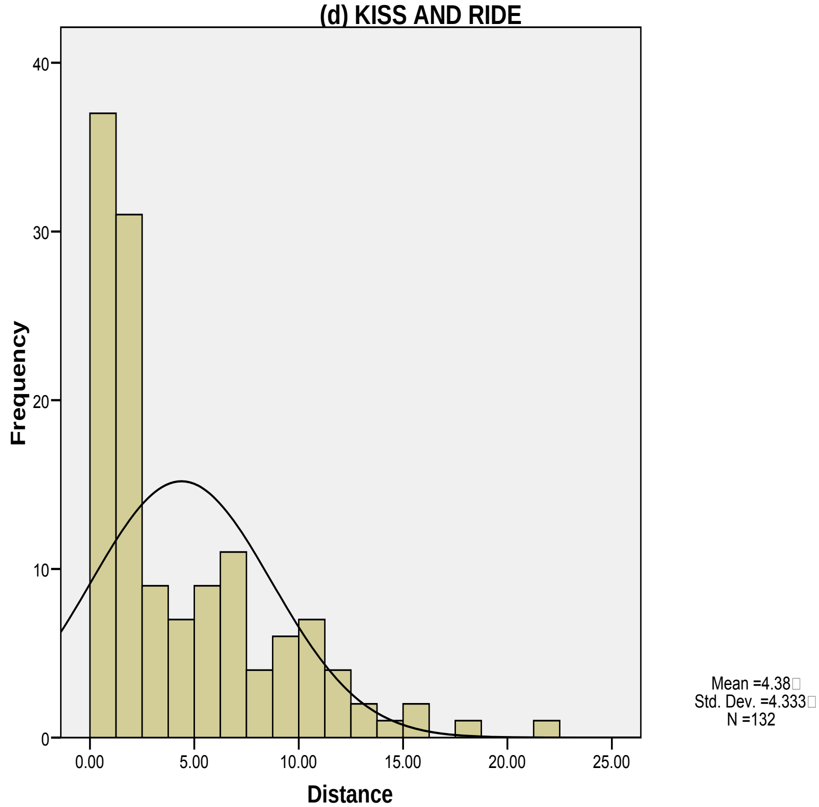


Figure 12. Distribution of Access Distance by Mode Choice (cont.)

4.3 Modeling Mode Choice

Before developing a comprehensive multinomial logit (MNL) model with multiple explanatory variables, we conducted bivariate analyses to test the relationships between mode choice and explanatory variables. We decided to estimate a simple MNL model for each independent variable. An alternative choice is analysis of variance (ANOVA), in which mode choice is the factor variable and other continuous variables (such as built environment elements) are dependent variables. The ANOVA assumes equal variance for factors. However, a preliminary analysis has shown that many variables in our data do not follow the equal variance assumption. Therefore, we chose MNL models instead of ANOVAs.

The MNL model is a deterministic utility model which is based on probability choice theory. The general form of a deterministic utility model is as follows (Koppelman and Bhat, 2006):

$$U_{it} = V_{it} + \varepsilon_{it} \qquad (1)$$

where U_{it} is the true utility of the alternative *i* to the decision maker *t*, V_{it} is the observable portion of the utility estimated by the model, and ε_{it} is the error or the portion of the utility unknown to the analyst.

In this context, a rider chooses a particular mode (rather than other modes) to access LRT stations because the observed utility derived from the choice of the particular mode exceeds the observed utility derived from the choice of other modes. In the MNL model, we assume that the error components are identically and independently distributed across alternatives and across observations, and the error term is Gumbel distributed. Therefore, the probability that a LRT rider chooses a particular access mode *i* can be expressed as:

$$P(i) = \frac{\exp(V_i)}{\sum_{j=1}^{J} V_j} \qquad (2)$$

where V_j is the observed component of the utility of alternative *j*, and it is a linear function of potential explanatory variables.

In the following MNL models, bus mode was chosen as the base alternative. Therefore, the interpretation of a coefficient is to compare with the choice of the bus mode. A positive coefficient for a variable means that as the variable increases a rider is more likely to use mode *i* than bus. When discussing MNL models, we chose the significance level of 0.05 as the critical value for the p-value. Further, these relationships are bivariate without controls. Therefore, the relationship may be confounded by other variables. In this section, those who walked to LRT stations and whose origins were more than a mile away from the stations were removed from mode choice analysis. Note that results from models indicate only association and we do not intend to make causal inference.

4.3.1 The correlation between the built environment on mode choice

The measurements of the built environment were derived from the data from MetroGIS DataFinder (http://www.datafinder.org/).

Table 9 illustrates the connection between mode choice and number of bus routes within a quarter mile of LRT stations. The latter variable is measured using the count of bus routes that are present in the one-quarter-mile buffer from LRT stations. Because the buffers for all stations have the same size, this variable can be treated as a measurement of bus route density. Number of bus routes is also an indicator of bus service quality. Generally, the higher the number of bus routes in an area, the larger the coverage of bus service to the area. The table shows that LRT riders were less likely to use walking or park and ride (than bus) to reach LRT stations with multiple bus routes; but there is no significant difference between the choices of bus and kiss and ride. Overall, increasing the number of feeder buses seems to promote bus access to LRT stations.

Table 9. The relationship between mode choice and number of bus routes

	Walk		Park and Ride		Kiss and Ride	
	coeff.	p-value	coeff.	p-value	coeff.	p-value
Intercept	-0.343	0.000	0.329	0.000	-1.681	0.000
Number of bus routes within ¼ mile	-0.004	0.000	-0.018	0.000	-0.002	0.321

A second indictor of bus service quality to an area is the number of bus stops within a prespecified distance of LRT stations. This variable is measured using the count of bus stops that are present in a buffer from LRT stations. We used four different buffers: a quarter mile, half a mile, a mile, and one and a half miles. Table 10 shows that LRT riders were more likely to walk to LRT stations with a large number of bus stops in a quarter-mile buffer, but they were less likely to use park and ride to reach the LRT stations; there is no significant difference between the choices of bus and kiss and ride. Here, a large number of bus stops may indicate a pedestrian-oriented environment and hence facilitate walking access.

Table 10. The relationship between mode choice and number of bus stops

	Walk		Park and Ride		Kiss and Ride	
	coeff.	p-value	coeff.	p-value	coeff.	p-value
Intercept	-0.359	0.000	0.251	0.000	-1.671	0.000
Number of bus stops within ¼ mile	0.001	0.000	-0.002	0.000	0.000	0.187

Miles of bikeway (including on-road and off-road bikeways, proposed and existing bikeways, and including bike lanes, bike-able road shoulders, and trails) within a buffer of LRT stations is a measurement of bike-friendliness. It can also act as a proxy for a pedestrian-friendly environment. This variable is measured using the cumulative miles of bikeways within a prespecified distance from LRT stations. We used three buffers: a quarter mile, half a mile, and a mile. We found that LRT riders were less likely to use driving (either park and ride or kiss and ride) to LRT stations with a large amount of bikeways in a quarter-mile buffer, but there is no significant difference between walk and bus modes (Table 11). We found similar results when we changed the buffer from a quarter mile to half a mile and a mile. Therefore, bike-friendly environment appears to discourage the mixing of driving-related modes with the LRT.

Table 11. The relationship between mode choice and miles of bikeway

	Walk		Park and Ride		Kiss and Ride	
	coeff.	p-value	coeff.	p-value	coeff.	p-value
Intercept	-0.213	0.038	0.962	0.000	-1.305	0.000
Cumulative miles of bikeway within ¼ mile	0.034	0.518	-0.793	0.000	-0.277	0.002

Number of four-way intersections within a buffer of LRT stations is a widely-used measurement of street connectivity. Generally, neighborhood streets are well connected with a large number of four-way intersections. This variable is measured using the count of four-way intersections within a prespecified distance of LRT stations. We used two buffers: half a mile and a mile. Again, since all buffers have the same size, the number of four-way intersections measures virtually intersection density. Generally, better street connectivity tends to produce less car traffic (Benfield et al., 1999). We found that riders were less likely to use driving-related modes to reach LRT stations with ample four-way intersections in a half-mile buffer, but there is no significant difference between walk and bus modes (Table 12). The findings are consistent with previous research.

Table 12. The relationship between mode choice and number of four-way intersections

	Walk		**Park and Ride**		**Kiss and Ride**	
	coeff.	p-value	coeff.	p-value	coeff.	p-value
Intercept	-0.316	0.003	1.393	0.000	-1.144	0.000
Number of four-way intersections within ½mile	0.002	0.082	-0.032	0.000	-0.010	0.000

Number of parking slots measures park and ride capacity of LRT stations. For Hiawatha LRT, there are three stations with park and ride facilities: 28th Avenue station, Fort Snelling station, and Lake Street station. Stations with parking facilities generally aim to serve driving population; the design of station areas is auto-oriented. Not surprisingly, we found that riders were more likely to use park and ride and kiss and ride to reach LRT stations with parking facilities, but there is no significant difference between walk and bus modes (Table 13).

Table 13. The relationship between mode choice and number of parking

	Walk		**Park and Ride**		**Kiss and Ride**	
	coeff.	p-value	coeff.	p-value	coeff.	p-value
Intercept	-0.152	0.002	-0.863	0.000	-1.892	0.000
Number of parking slots	0.000	0.850	0.005	0.000	0.002	0.000

Land use mix is measured using an entropy index. The index is defined as the following:

$$\text{Land use mix} = \frac{-\sum_{i=1}^{n}(p_i)\ln(p_i)}{\ln(n)} \quad (3)$$

where p_i is the proportion of *i*th type of land use in the measurement area, and *n* is the number of types of land use (Song, 2005). Here, land use types include residential, commercial, industrial, office/institutional, and other uses (n = 5). This index ranges from 0 (homogenous use) to 1 (each use accounts for 20%). We measured land use mix using two buffers: half a mile and a mile. We found that riders were less likely to walk to mixed-use LRT stations, presumably because fewer residents lived in mixed-use neighborhoods and there are good bus connections in the neighborhoods; they were less likely to use park and ride to reach LRT stations; but there is no significant difference between bus and kiss and ride modes (Table 14). Overall, it seems that LRT stations with mixed-use development tend to encourage bus connections.

Table 14. The relationship between mode choice and land use mix

	Walk		Park and Ride		Kiss and Ride	
	coeff.	p-value	coeff.	p-value	coeff.	p-value
Intercept	1.467	0.000	1.656	0.000	-1.587	0.000
Land use mix within ½ mile	-2.249	0.000	-2.486	0.000	-0.217	0.664

Distance is an important variable that influences mode choice (Koppelman and Bhat, 2006). The distance from trip origin to LRT stations is measured using the network distance function of ArcGIS. Network Analyst Extension utilizes a street network of the Metro area to create the shortest-distance route between trip origin and boarding LRT station. One-way restrictions are used in the network when modeling all transit modes except walking. Due to the large amount of trips, the process is automated by using ArcGIS Model Builder. We found that riders were more likely to drive to distant LRT stations and less likely to walk to those stations, as expected (Table 15).

Table 15. The relationship between mode choice and distance to LRT stations

	Walk		Park and Ride		Kiss and Ride	
	coeff.	p-value	coeff.	p-value	coeff.	p-value
Intercept	3.442	0.000	-1.327	0.000	-2.235	0.000
Distance to LRT stations	-4.278	0.000	0.198	0.000	0.089	0.000

Overall, the bivariate analyses between mode choice and each of built environment elements show that if the goal is to promote bus access, we should encourage mixed-use development, create an attractive environment for non-motorized mode, improve street connectivity, and increase the coverage of feeder services; if the goal is to attract more choice riders, park and ride facilities should be provided (Table 16).

Table 16. An overview of built environment elements

Variables	Walk	Park and Ride	Kiss and Ride
Land use mix	–	–	0
Parking capacity	0	+	+
Number of four-way intersections	+	–	–
Bikeway length	+	–	–
Number of bus stops	+	–	0
Number of bus routes	–	–	0
Distance to LRT stations	–	+	+

Notes: "-" means negative impacts, "+" indicates positive impacts, and "0' means the impact is insignificant. Bus is the reference category.

We found an interesting pattern when we compared the goodness-of-fit measurement of the MNL models with explanatory variable being measured at different buffers. As the size of the buffer increases, the McFadden R-square (= 1- (log-likelihood at convergence)/(log-likelihood at constant) grows (Table 17). Therefore, although the literature often uses built environment measurements at ¼ and ½ mile buffers, the environment at a larger geographical scale seems to carry more explanatory power. This finding suggests that riders may evaluate an area beyond the surroundings of LRT stations when making decisions on mode choice. Note, this pattern does not hold for social environment variables, however.

Table 17. McFadden R-square of MNL models

	Number of bus stops	Miles of bikeway	Number of 4-way intersections	Land use mix
0.25 mile buffer	0.049	0.047	-	-
0.5 mile buffer	0.053	0.082	0.093	0.018
1 mile buffer	0.06	0.089	0.108	0.034
1.5 mile buffer	0.075	-	-	-

4.3.2 The connection between the social environment on mode choice

The 2000 Census data were used to measure the social environment around LRT stations (factfinder.census.gov/). The census data are accurate at the census block group level; the data at the block level were intentionally manipulated to ensure confidentiality. However, the area of census block groups is too large for such a station-wide analysis. Therefore, when measuring the social environment, we chose to use the data at the census block level. If more than 50% of a census block is within a prespecified buffer, the block was included in the buffer; otherwise, it was excluded from the buffer. Although the blocks included in the measurement do not exactly match the buffer area, we do not expect significant variations in such a small geographic area. The social environment variables were measured at two different buffers: half a mile and a mile.

Population density is commonly used as an environmental measurement. It is measured as the number of persons per acre. Generally, population density is positively associated with walking and bus use, but has a negative association with driving. Here, we found that riders were less likely to drive (either park and ride or kiss and ride) to LRT stations with high population density, but were more likely to walk to those stations (Table 18).

Table 18. The relationship between mode choice and population density

	Walk		Park and Ride		Kiss and Ride	
	coeff.	p-value	coeff.	p-value	coeff.	p-value
Intercept	0.119	0.153	1.243	0.000	-1.039	0.000
Population density within ½ mile	-0.036	0.000	-0.272	0.000	-0.105	0.000

The proportion of African Americans was measured as the share of African Americans accounting for the total population in the buffer area. Compared to other three modes, stations with a higher share of African Americans also had a higher likelihood of riders taking the bus to reach the LRT stations (Table 19). The population ethnicity mix is an entropy index defined similarly to the land use mix index in Section 4.3.1:

$$\text{Population ethnicity mix} = \frac{-\sum_{i=1}^{n}(p_i)\ln(p_i)}{\ln(n)} \quad (4)$$

where p_i is the proportion of *i*th type of ethnicity in total population, and *n* is the number of types of ethnicity and race. In this study, the ethnicity and race include Whites, Africans, Asians, Hispanics, and others. The relationships between mode choice and population mix are similar to those between mode choice and proportion of African Americans (Table 20).

Table 19. The relationship between mode choice and proportion of African Americans

	Walk		Park and Ride		Kiss and Ride	
	coeff.	p-value	coeff.	p-value	coeff.	p-value
Intercept	0.092	0.361	1.403	0.000	-1.147	0.000
Proportion of African Americans within ½ mile	-0.013	0.006	-0.113	0.000	-0.035	0.000

Table 20. The relationship between mode choice and population ethnicity mix

	Walk		Park and Ride		Kiss and Ride	
	coeff.	p-value	coeff.	p-value	coeff.	p-value
Intercept	1.204	0.000	2.348	0.000	-0.811	0.005
Population ethnicity mix within ½ mile	-2.272	0.000	-4.428	0.000	-1.541	0.001

Median household income, the proportion of people under poverty, and median value of owner-occupied housing units are commonly used as proxies for the social environment. Tables 21-23 show that median household income is negatively associated with the use of walking mode, but has a positive association with Park/Kiss and Ride modes. In contrast, the share of people under poverty is negatively associated with the two modes. Further, median housing values have negative associations with walking Access and park and Ride mode.

Table 21. The relationship between mode choice and median household income

	Walk		Park and Ride		Kiss and Ride	
	coeff.	p-value	coeff.	p-value	coeff.	p-value
Intercept	0.295	0.008	-1.985	0.000	-2.569	0.000
Median household income ($1,000)	-0.015	0.000	0.052	0.000	0.024	0.000

Table 22. The relationship between mode choice and proportion of people under poverty

	Walk		Park and Ride		Kiss and Ride	
	coeff.	p-value	coeff.	p-value	coeff.	p-value
Intercept	-0.086	0.358	1.039	0.000	-1.131	0.000
Proportion of people under poverty within ½ mile	-0.004	0.394	-0.083	0.000	-0.038	0.000

Table 23. The relationship between mode choice and median housing value

	Walk		Park and Ride		Kiss and Ride	
	coeff.	p-value	coeff.	p-value	coeff.	p-value
Intercept	0.222	0.191	0.250	0.138	-2.035	0.000
Median housing value ($1,000,000)	-4.141	0.021	-4.122	0.021	3.054	0.381

4.3.3 The relationship between rider and trip characteristics and mode choice

Socio-demographic characteristics of LRT riders are expected to impact how they access LRT stations, as shown in many studies (e.g., Kim et al., 2007). We found that captive riders (who do not have vehicles or driver's licenses) were more likely to take bus to reach LRT stations. We also found that household income was positively associated with the choice of walking, park and ride, or kiss and ride. In addition, women were more likely to be dropped off at LRT stations (Tables 24-26).

Table 24. The relationship between mode choice and captive riders

	Walk		Park and Ride		Kiss and Ride	
	coeff.	p-value	coeff.	p-value	coeff.	p-value
Intercept	0.292	0.000	0.599	0.000	-1.247	0.000
Captive riders	-1.396	0.000	-3.813	0.000	-1.360	0.000

Table 25. The relationship between mode choice and household income

	Walk		Park and Ride		Kiss and Ride	
	coeff.	p-value	coeff.	p-value	coeff.	p-value
Intercept	-1.465	0.000	-2.341	0.000	-3.190	0.000
Household income	0.346	0.000	0.569	0.000	0.394	0.000

Table 26. The relationship between mode choice and gender

	Walk		Park and Ride		Kiss and Ride	
	coeff.	p-value	coeff.	p-value	coeff.	p-value
Intercept	-0.174	0.011	-0.200	0.004	-2.079	0.000
Gender	-0.094	0.336	0.064	0.509	0.518	0.004

Does the access mode of LRT riders differ by trip purposes? Our results showed that for home-based work trips, LRT riders were more likely to use walking and park and ride to reach LRT stations, but there is no significant difference between bus and kiss and ride modes (Table 27). For home-based university trips, LRT riders were more likely to take a bus to LRT stations and there are no differences between bus and park and ride, and between bus and kiss and ride (Table 28). For home-based school trips, riders were more likely to take a bus to reach LRT stations, although the difference between bus and kiss and ride modes is significant only at the 0.10 level (Table 29). For home-based other trips, LRT riders were less likely to walk to LRT stations, and there are no differences between bus and driving-related modes (Table 30). For home-based shopping trips, there are no significant differences in the choice of access mode (results not shown). For non-home-based work trips, LRT riders were more likely to access stations by walking and kiss and ride, but were less likely to park their vehicles at the stations (Table 31). For non-home-based other trips, riders were less likely to use park and ride mode to reach LRT stations, but were more likely to be dropped off (Table 32).

Overall, the kiss and ride mode is more likely to be used when neither end of the trip is home. The park and ride mode is more likely to be used by home-based commuters and is more likely to occur during peak hours. We also found that work trips are positively associated with walking access to LRT stations. In addition, frequent LRT riders were more likely to take bus to reach LRT stations (Tables 33 and 34).

Table 27. The relationship between mode choice and home-based work trips

	Walk		Park and Ride		Kiss and Ride	
	coeff.	p-value	coeff.	p-value	coeff.	p-value
Intercept	-0.332	0.000	-0.491	0.000	-1.675	0.000
Home-based work trips	0.274	0.005	0.430	0.000	-0.138	0.408

Table 28. The relationship between mode choice and home-based university trips

	Walk		Park and Ride		Kiss and Ride	
	coeff.	p-value	coeff.	p-value	coeff.	p-value
Intercept	-0.110	0.027	-0.252	0.000	-1.705	0.000
Home-based university trips	-0.840	0.000	0.132	0.383	-0.474	0.135

Table 29. The relationship between mode choice and home-based school trips

	Walk		Park and Ride		Kiss and Ride	
	coeff.	p-value	coeff.	p-value	coeff.	p-value
Intercept	-0.133	0.006	-0.183	0.000	-1.711	0.000
Home-based school trips	-1.401	0.000	-3.748	0.000	-1.122	0.061

Table 30. The relationship between mode choice and home-based other trips

	Walk		Park and Ride		Kiss and Ride	
	coeff.	p-value	coeff.	p-value	coeff.	p-value
Intercept	-0.141	0.005	-0.227	0.000	-1.750	0.000
Home-based other trips	-0.329	0.040	-0.085	0.582	0.028	0.915

Table 31. The relationship between mode choice and non home-based work trips

	Walk		Park and Ride		Kiss and Ride	
	coeff.	p-value	coeff.	p-value	coeff.	p-value
Intercept	-0.253	0.000	-0.214	0.000	-1.828	0.000
Non-home-based work trips	0.882	0.000	-0.479	0.043	0.893	0.001

Table 32. The relationship between mode choice and non home-based other trips

	Walk		Park and Ride		Kiss and Ride	
	coeff.	p-value	coeff.	p-value	coeff.	p-value
Intercept	-0.182	0.000	-0.194	0.000	-1.801	0.000
Non-home-based other trips	0.115	0.543	-1.043	0.043	0.618	0.026

Table 33. The relationship between mode choice and peak period or not

	Walk		Park and Ride		Kiss and Ride	
	coeff.	p-value	coeff.	p-value	coeff.	p-value
Intercept	-0.244	0.000	-0.412	0.000	-1.870	0.000
Peak period	-0.032	0.732	0.357	0.000	0.132	0.421

Table 34. The relationship between mode choice and bus frequency

	Walk		Park and Ride		Kiss and Ride	
	coeff.	p-value	coeff.	p-value	coeff.	p-value
Intercept	0.417	0.021	0.736	0.000	-0.208	0.410
Bus frequency	-0.160	0.000	-0.223	0.000	-0.390	0.000

4.3.4 Comprehensive MNL models for mode choice

As mentioned earlier, bivariate analysis can establish evidence for the association between mode choice and each explanatory variable, but it cannot eliminate the potential spurious effect. That is, their association may be due to confounding factors. To explore influential elements of the built and social environments and to test the importance of these variables, MNL models incorporating various environmental measurements are in order. It is also important to control for socio-demographic and other variables, since some of the differences observed in the previous subsections may be due to differences in those variables. When we developed the model, potential explanatory variables were entered into the model in groups, starting with socio-demographic factors, followed by trip-related characteristics, built environment elements, and social environment elements. At each step, insignificant variables were dropped and the model was re-estimated before the next set of variables was entered. Generally, the significance level of 0.05 was chosen to determine if a variable entered the final model, although several variables in the model have p-values greater than 0.05 but smaller than 0.1. It is worth noting that elements of the built and social environments are highly correlated with each other. Incorporating both built environment elements and social environment elements produced the problem of multicollinearity. Therefore, we estimated two MNL models for mode choice: Model 1 includes socio-demographics, trip characteristics, trip distance, and built environment attributes; Model 2 contains socio-demographics, trip characteristics, trip distance, and social environment attributes.

The pseudo R-square for Model 1 is 0.553, suggesting that 55.3% of information in the data is explained by the model. The model showed that riders' socio-demographics influence their mode choice (Table 35). In particular, household income is positively associated with the choice of park and ride and kiss and ride; LRT riders with more vehicles in the household were more likely to use walking, park and ride, or kiss and ride than bus to reach LRT stations; riders with a driver's license are more likely to walk to or park their cars at LRT stations; female riders are more likely to use driving-related modes (either as a driver or a passenger) to reach LRT stations; by contrast, riders in a large household were less likely to use driving-related modes; riders with more workers in the household were more likely to use walking and kiss and ride to reach LRT stations. Further, riders who frequently took LRT were less likely to use driving-related modes to reach LRT stations. If a trip was for home-based school, LRT riders were less likely to walk to LRT stations. In contrast, if a trip was a home-based other trip, riders were more likely to walk to LRT stations, but were less likely to use park and ride mode.

As expected, the distance from trip origin to LRT stations has a negative association with walking, but it is positively associated with park and ride and kiss and ride modes. After controlling for these variables, the built environment around LRT stations also impacts mode choice. Number of bus stops within a buffer of one and half miles is negatively associated with the choice of driving-related modes. Number of four-way intersections within a half-mile buffer negatively affects the choice of walking, compared to bus. So does the mixed-use indicator within a half-mile buffer. Number of parking spaces tended to discourage the use of bus but increase the probability of choosing walking, park and ride, or kiss and ride.

Overall, socio-demographic and trip characteristics, the distance from origin to destination, and built environment elements around LRT stations influence mode choice of the trip access to LRT stations. Which group of variables is more important in explaining the variation in mode choice? To answer this question, we estimated a series of MNL models with different combinations of groups of explanatory variables and evaluated the contribution of these variables to the goodness-of-fit measure (Table 36). We found that the distance variable explains 26.6~35.8% of the information in the data; built environment elements explain 6.6~17.8% of the information in the data; socio-demographic and trip characteristics explain 10~13% of the information in the data. It is natural that distance (an indicator of travel costs) is the most important variable that determines mode choice. On the other hand, the effects of built environment elements are somewhat equivalent to socio-demographic and trip characteristics. In other words, if the goal of a policy is to encourage mode mixing, the built environment around LRT stations can play an important role.

Table 35. MNL model for mode choice (without social environment variables)

	Walk		**Park and Ride**		**Kiss and Ride**	
	coeff.	p-value	coeff.	p-value	coeff.	p-value
Intercept	4.589	0.000	-4.027	0.000	-3.019	0.000
Household income	0.098	0.148	0.187	0.006	0.334	0.000
Number of workers in Household	0.235	0.064	-0.216	0.118	0.318	0.039
Gender	0.040	0.825	0.380	0.043	0.897	0.000
Have license	0.473	0.061	2.161	0.000	0.276	0.406
Number of vehicles in household	0.245	0.033	1.101	0.000	0.338	0.013
Household size	-0.088	0.252	-0.228	0.006	-0.179	0.078
Bus frequency	0.022	0.802	-0.267	0.001	-0.347	0.000
Home-based school trips	-1.297	0.014	-1.855	0.196	-0.505	0.528
Non-home-based other trips	0.664	0.091	-0.866	0.089	0.292	0.537
Distance to LRT stations	-4.883	0.000	0.152	0.000	0.087	0.002
Number of bus stops within 1½ mile	0.000	0.270	-0.0006	0.000	0.000	0.526
Number of four-way intersections within ½ mile	-0.015	0.007	0.000	0.940	-0.003	0.703
Number of parking	0.002	0.015	0.004	0.000	0.003	0.000
Land use mix within ½ mile	-1.856	0.000	0.767	0.143	-0.116	0.858
Pseudo R-square	0.553					

N=1961

Table 36. The importance of explanatory variables

Explanatory Variables	Pseudo R^2	Note
Model 1	0.553	
Demographics only	0.13	0.13 is the upper boundary of the effect of demographics
Built Environment only	0.178	0.178 is the upper boundary of the effect of built environment
Distance only	0.358	0.358 is the upper boundary of the effect of distance
Built Environment + distance	0.453	0.10=0.553-0.453 is the lower boundary of the effect of demographics
Built Environment + Demographics	0.287	0.266=0.553-0.287 is the lower boundary of the effect of distance
Demographics + distance	0.487	0.066=0.553-0.487 is the lower boundary of the effect of built environment

Model 2 shows the results of MNL model with built environment elements being replaced by social environment variables (Table 37). The impacts of socio-demographic and trip characteristics on mode choice in Model 2 are similar to those in Model 1. We also found that age is negatively associated with the choice of park and ride and kiss and ride. For social environment elements, we found that riders were more likely to take a bus to reach LRT stations with higher population density; and riders were more likely to drive (either as a driver or a passenger) but were less likely to walk to LRT stations in high-income area. In terms of the importance of different groups of variables, we found that the distance remains the most important influential variable, and that socio-demographic and trip characteristics tend to be somewhat superior to social environment elements.

Table 37. MNL model for mode choice (without built environment variables)

	Walk		Park and Ride		Kiss and Ride	
	coeff.	p-value	coeff.	p-value	coeff.	p-value
Intercept	3.461	0.000	-4.915	0.000	-3.150	0.000
Distance to LRT stations	-4.687	0.000	0.154	0.000	0.089	0.003
Household income	0.122	0.079	0.250	0.000	0.367	0.000
Number of workers in Household	0.187	0.146	-0.349	0.009	0.253	0.111
Gender	0.023	0.898	0.352	0.042	0.889	0.000
Have license	0.570	0.023	2.692	0.000	0.494	0.140
Number of vehicles in household	0.296	0.009	1.134	0.000	0.364	0.009
Household size	-0.102	0.175	-0.262	0.001	-0.202	0.046
Home-based school trips	-1.327	0.012	-2.647	0.093	-0.805	0.333
Non-home-based other trips	0.532	0.170	-0.948	0.072	0.201	0.683
Bus frequency	0.030	0.737	-0.119	0.146	-0.348	0.000
Age	-0.073	0.324	-0.149	0.026	-0.167	0.058
Population density within ½ mile	-0.053	0.003	-0.153	0.000	-0.054	0.027
Median household income with ½ mile (unit: $1000)	-0.011	0.071	0.047	0.000	0.020	0.023
Pseudo R-square	0.525					

N=1957

Overall, the importance of variables in influencing mode choice can be roughly expressed as: the distance from origins to stations >> socio-demographic and trip characteristics ≈ built environment elements around the stations > social environment elements around the stations.

5. CONCLUSIONS

This project studied the profile of transit riders in the Twin Cities and explored environmental factors that influence mode choice of access to transitways (the Hiawatha Light Rail Transit), using the 2005 Transit Rider Survey conducted by Metropolitan Council.

We classified transit services in the region into four categories: Premium Express, Express Bus, LRT, and Local Bus. Generally, we found that premium express had the highest percentage of choice riders (those who have a driver's license and have cars in the household) and the Hiawatha LRT ranked third, with 59% of users being choice riders. On the other hand, the LRT balances efficiency (by attracting choice riders) and equity (through promoting reverse commute and serving captive riders). In addition, a 2005 survey by the Metro Transit showed that about 40% of light rail riders were new transit users (Light Rail Now, 2005). Therefore, the LRT has the ability to attract choice riders. Combining with the fact that riders were driving past express bus locations with direct service into downtown in order to take the LRT (as shown in the travel shed analysis), this finding seems to provide supportive evidence for "rail bias" – people who do not take bus will take the rail. The LRT has facilitated the formation of a multi-modal transportation system by promoting mode mixing and encouraging transfer between the LRT and other types of transit services.

More importantly, travel shed analysis has showed that the LRT has a much broader influence on the regional transportation network than local buses and express services: local buses mainly serve a narrow corridor along the route; express services serve riders from limited communities at the suburban end; the LRT serves the Hiawatha corridor but also serves riders from the whole region. In other words, the LRT plays an important role in improving regional accessibility. Further, an overlay of travel sheds for the existing buses along University Avenue shows great potential for the Central Corridor in promoting regional accessibility.

Regarding mode choice of access to transit, we found that riders of express services were more likely to use park and ride to reach transit than those of other types of services; local bus riders were more likely to walk to bus stops than other types of services, whereas access mode of LRT riders tended to be balanced. We also found that about 75% of riders walked farther than 0.25 miles to reach LRT stations, a critical value of walking distance widely considered by transportation planners.

MNL models for access mode choice of the Hiawatha LRT confirmed that riders' demographics, trip characteristics, built environment elements and social environment factors around LRT stations affect the choice of access modes. Among these groups of variables, the distance from trip origin to LRT stations is the dominant factor that influences mode choice. We also found that the impacts of built environment elements on mode choice were equivalent to those of riders' demographics and trip characteristics, whereas the effects of social environment factors on mode choice were the weakest.

The mode choice analysis also provides some implications if we want to use the built environment to promote mode mixing. In particular, if the goal is to maximize the number accessing transitways from existing bus services, we should increase the coverage of feeder services, increase street connectivity and promote mixed-use development. If the goal is to attract choice riders in areas where walking and local transit are not options, more park and ride facilities should be provided. Our results showed that it is efficient to provide feeder services in the corridor within 2 miles of the LRT line. Further, it is not only station areas but also the location of stations areas that affect mode choice of access to the LRT stations.

Overall, the introduction of the Hiawatha LRT in the Twin Cities has made an immediate splash in promoting transit ridership. In 2008, the Hiawatha LRT ridership reached 10 million for the first time and increased by 12.3%, compared to 2007. Although the increase in ridership may partly result from skyrocketing gas prices during the first half of 2008, the growth of LRT ridership greatly exceeds that of other types of transit (the ridership of the whole Metro increased by 6.7%; express bus ridership grew by 10.7%) (Metropolitan Council, 2009). Further, the Hiawatha LRT has contributed to economic development (Goetz et al., 2008; Metropolitan Council, 2006). These facts point to the success of the Hiawatha LRT.

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