Estimated Running Time and Demand for a Bus Rapid Transit Corridor

Final Report

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Due to the increasing ease and affordability of intelligent transportation systems (ITS) data collection, new methods for assessing conditions along current and future transit corridors are available. Measures such as average speed, travel time, and intersection delay can be determined for car and bus traffic along a corridor using readily available technology. These measures can be used to monitor the performance of the transportation system for existing modes and to estimate measures for proposed additions to the system.

The goal of this research is to utilize GPS device records from regular vehicles as well as busses to estimate running time and potential passenger demand for a proposed Bus Rapid Transit (BRT) corridor on Cedar Avenue in the southern Twin Cities Metropolitan Area. Demand for future BRT service is predicted based on frequency and reliability of service and socio-demographic characteristics of the region around the corridor. Average passenger counts for existing transit service along the corridor in combination with existing commuting patterns in the region are used to estimate passenger demand.

The running time and demand models produced by this study can be integrated with existing cost benefit software to evaluate the effects of intelligent transportation systems technologies on BRT running time (IBAT). The findings of this research introduce a benchmark for comparison between transit and private vehicle running time for general applications in Hennepin County. These findings also help to create additional understanding of the potential for BRT service in the Twin Cities region.
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EXECUTIVE SUMMARY

Due to the increasing ease and affordability of intelligent transportation systems (ITS) data collection, new methods for assessing conditions along current and future transit corridors are available. Measures such as average speed, travel time, and intersection delay can be determined for car and bus traffic along a corridor using readily available technology. These measures can be used to monitor the performance of the transportation system for existing modes and to estimate measures for proposed additions to the system.

The goal of this research is to estimate running time and potential passenger demand for a proposed Bus Rapid Transit (BRT) corridor on Cedar Avenue in the southern Twin Cities Metropolitan Area. Running time during peak and off peak hours is estimated based on GPS data obtained from existing transit service and probe vehicles running along the corridor. This approach expands upon previous work comparing the effectiveness of using buses and probe vehicles to evaluate corridor levels of service and allows for a comparison of service running times provided by different modes.

Demand for future BRT service is predicted based on frequency and reliability of service and socio-demographic characteristics of the region around the corridor. Average passenger counts for existing transit service along the corridor in combination with existing commuting patterns in the region are used to estimate passenger demand.

The running time and demand models produced by this study can be integrated with existing cost benefit software to evaluate the effects of intelligent transportation systems technologies on BRT running time (IBAT). The findings of this research introduce a benchmark for comparison between transit and private vehicle running time for general applications in Hennepin County. These findings also help to create additional understanding of the potential for BRT service in the Twin Cities region.
INTRODUCTION

As fuel prices and congestion levels continue to rise, an increasing number of new transit services are being proposed to address concerns and make transit a viable option for a larger portion of the population. The success of these new transit lines and modes, however, depends primarily upon the running time, frequency, and reliability of the service. As a result, reliable and cost-effective methods of estimating running time and passenger demand for new transit corridors are of vital importance to ensure efficient and successful planning.

The primary objective of this research is to better understand the factors affecting bus transit service demand and travel time in order to estimate running time and potential demand for proposed bus rapid transit (BRT) service along a specific corridor in the Twin Cities Minnesota region. BRT is similar to regular bus service, but can provide a higher quality of service at a lower cost than streetcar or light rail systems. This increased service quality is mainly due to increased service frequency and reduced running time resulting from increased stop spacing, dedicated lanes, and implementation of Intelligent Transportation Systems (ITS) technologies (e.g., improved vehicle design, “smart card” fare collection, signal priority systems).

In the Twin Cities region, the increase in transit ridership due to the opening of the Hiawatha Light Rail Corridor showed potential for implementing high frequency transit corridors, including BRT service, on similar corridors. The Metropolitan Council’s 2030 Transit Study recommends that BRT be explored for nine corridors in the Twin Cities Metropolitan Area, while at the time of this study it only identified four corridors as having potential for LRT (Hiawatha, Central, Southwest, and Northwest (Bottineau)) (Metropolitan Council, 2004). When this research project began, the research team was assigned to examine conditions along Bottineau Boulevard, a proposed BRT corridor in the northwest metro area. For this study, the research team partnered with Metro Transit to collect running time and passenger demand data for existing bus service on Bottineau Boulevard and similar transit corridors in the northwest metro using Metro Transit’s extensive ITS systems (i.e., automatic vehicle locators and passenger counters). However, midway through the study plans to construct BRT in this area were put on hold and the Bottineau Boulevard corridor has since been identified as one of the two corridors in the Twin Cities area on which passenger demand is large enough that LRT service, as opposed to BRT, should be considered (Metropolitan Council, 2004). As a result, the scope of this study was changed and is now focused on the Cedar Avenue BRT corridor in the southeastern metro. Regardless, the preliminary results from the Bottineau Boulevard analysis are included in Appendix C.

For this new phase of the study the research team partnered with the Minnesota Valley Transit Authority (MVTA) to estimate potential demand and running time for the proposed Cedar Avenue Busway, a 16-mile BRT corridor running south from the Mall of America LRT transit station in Bloomington to the outer-ring suburb of Lakeville. The Cedar Avenue Busway will be deployed in phases beginning in 2009. These phases will gradually enhance existing bus service on the corridor (provided by MVTA) through the addition of bus only lanes/shoulders, park and ride stations, new ITS-equipped buses, and consolidated stops. Unfortunately, MVTA buses are not currently equipped with ITS systems similar to those available on Metro Transit buses; as a result, the research team had to develop new methodologies for estimating running times and passenger demands along this corridor using handheld Global Positioning System (GPS) units and manual passenger counts.
When completed, the Cedar Avenue Busway will run south from the Mall of America LRT transit station along Cedar Avenue / Highway 77 through Apple Valley to Lakeville. This corridor is one of the fastest growing areas in the state of Minnesota and is projected to experience a large growth in traffic and congestion over the next 20 years. Average daily traffic volumes on the corridor currently exceed 100,000 vehicles. Another 90,000 vehicles are expected to use the corridor each day by 2025. This increase will make congestion a concern along the entirety of Cedar Avenue, especially around the Minnesota River Bridge where traffic back-ups already extend as far as seven miles during peak hours (Dakota County, 2006).

The remainder of this report will summarize the current literature related to estimating transit passenger demand and running time, the travel time and demand benefits of BRT over traditional bus service, and some of the ITS technologies typically implemented with BRT service. The report will then describe the data collected to estimate BRT passenger demand and running time, outline a detailed research methodology, and present the results of a generalized passenger demand analysis and several regression models examining the relationship between vehicle type, route characteristics, and travel time. Finally, the report will conclude by discussing the implications of these analyses for the Cedar Avenue Busway and other proposed BRT corridors and recommending how data from more advanced transit data collection systems could be used to enhance future analyses.
LITERATURE REVIEW

Transit Demand

There are two general types of people who ride transit. The first is captive riders who do not have other modes to choose from except transit. The second type is people who have access to alternative modes for their activities but they choose transit because it is convenient, cost efficient, or for other reasons. The factors affecting passengers’ decision to use transit versus other modes are affected by several costs including monetary costs (fares), the cost of travel time, cost of access and egress time, effort, and finally the cost of passenger discomfort. The Transit Capacity and Quality of Service Manual (TCQSM) provides a comprehensive approach to understanding the transit trip decision making processes, which includes several transit availability factors. These factors address the spatial and temporal availability of service at both ends of the trip (origins and destinations) (Kittelson & Associates 2003). The presence or absence of transit service near origin and destination is found by Murray (2001) to be a major factor in choosing transit as a mode for travel.

Transit demand is also related to the number of potential users along a route (e.g., place of residence, place of work, and various transit amenities such as park and ride or transfer). Levinson (1985) developed a model to forecast ridership along bus transit routes. His model is based on the following variables: passenger activity, population, employment, travel time, and demand elasticity factors. Levinson estimates bus ridership as a function of car ownership and walking distance to bus stops. Some scholars relate ridership to access, the more accessible the bus stops are the higher the usage (Hsiao, Lu et al. 1997; Polzin, Pendyala et al. 2002). This might not always be the case since ridership depends on additional variables such as service variability and /or socio-demographic information. The variability and frequency of service represent two additional basic factors that affect demand at a stop.

Several studies have contradictory outputs regarding the elasticity of demand for transit. Some studies indicate that average running time increases passenger demand more than other variables (Lago, Mayworm et al. 1981; Rodriguez and Ardila 2002); however, this is based on the understanding that most of transit users are captive riders. Other studies indicate that passengers are more sensitive to out of vehicle time (Kemp 1973; Pushkarev and Zupan 1977; Lago and Mayworm 1981; Mohring, Schroeter et al. 1987). Two comprehensive studies regarding the elasticity of demand with respect to fare change found that demand for transit service is inelastic when it comes to changes in price (Goodwin 1992; Oum, Waters II et al. 1992). The value associated to time is usually higher than the fare. Mohring et al. (1987) found the value associated with in vehicle time is around half the equivalent of an hourly wage, while wait time is valued at 2-3 times that of in vehicle time. Domencich, Kraft, and Valette (1968) estimate the elasticities of demand for public transit in relation to all aspects of time and cost. They found that passenger demand will decrease by 3.9% for a 10% increase in travel time, while demand will decrease by 7% for each 10% increase in access, egress, and waiting time. These findings were reported and validated later by Kraft and Domencich (1972) and O'Sullivan (2000). Another recent study used a service quality index to quantify passenger satisfaction with bus service in New South Wales, Australia. This study concludes that running time and fare are the greatest source of dissatisfaction, while frequency of service and seating availability had the largest positive impact on passenger satisfaction. The study indicates that access time to bus
stops when combined with the frequency of service are important aspects influencing transit demand (Hensher, Stopher et al. 2003).

Modifications in route design have been recommended by various researchers as means to increase transit demand and improve reliability. One example of this approach is to design shorter routes with fewer stops to decrease overall route complexity (Abkowitz and Engelstein 1984; Strathman and Hopper 1993). This approach is very similar to the changes proposed along the Cedar Avenue Busway, converting existing bus routes to simplified BRT service. However, it should be noted that this approach might lead to an increase in total trip time for some passengers, since they might need to transfer more with shorter routes. Most previous researchers use simulation to demonstrate the effects of bus stop consolidation on service reliability (Furth and Rahbee 2000; Saka 2001). These studies predicted improvements in service reliability and savings in travel time following bus stop consolidation.

**Travel / Running Time**

Running time, or travel time, is the amount of time it takes a bus to travel along its route. Abkowitz and Engelstein (1984) found that mean travel time is affected by route length, passenger activity, and number of signalized intersections. Most researchers agree on the basic factors affecting bus travel times (Abkowitz and Engelstein 1983; Guenthner and Sinha 1983; Levinson 1983; Abkowitz and Tozzi 1987; Strathman, Dueker et al. 2000). Table 1 contains a summary of factors affecting travel times.

**Table 1: Factors Affecting Transit Travel Times**

<table>
<thead>
<tr>
<th>Variables</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance</td>
<td>Segment length</td>
</tr>
<tr>
<td>Intersections</td>
<td>Number of signalized intersections</td>
</tr>
<tr>
<td>Bus stops</td>
<td>Number of bus stops</td>
</tr>
<tr>
<td>Boarding</td>
<td>Number of passenger boardings</td>
</tr>
<tr>
<td>Alighting</td>
<td>Number of passenger alightings</td>
</tr>
<tr>
<td>Time</td>
<td>Time period</td>
</tr>
<tr>
<td>Driver</td>
<td>Driver experience</td>
</tr>
<tr>
<td>Period of service</td>
<td>How long the driver has been on service in the study period</td>
</tr>
<tr>
<td>Departure delay</td>
<td>Observed departure time minus scheduled</td>
</tr>
<tr>
<td>Stop delay time</td>
<td>Time lost in stops based on bus configuration (low floor etc.)</td>
</tr>
<tr>
<td>Nonrecurring events</td>
<td>Lift usage, bridge opening etc.</td>
</tr>
<tr>
<td>Direction</td>
<td>Inbound or outbound service</td>
</tr>
<tr>
<td>Weather</td>
<td>Weather related conditions</td>
</tr>
</tbody>
</table>
Since buses travel with regular traffic, they are affected by the overall dynamics of the transportation system, where changes occur on both regular (i.e., peak hour traffic congestion) and random (i.e., road construction, accidents, special events) bases. These changes influence the amount of time it takes a bus to travel from one stop to another and the level of service it provides to passengers. Dwell time and passenger activity variables, such as boarding and alighting rates, also contribute to running time (Guenthner and Sinha 1983; Levinson 1983; Guenthner and Hamat 1988; Strathman, Dueker et al. 2000; Rodriguez and Ardila 2002; McKnight, Levinson et al. 2003; Bertini and El-Geneidy 2004; Dueker, Kimpel et al. 2004). Agencies try to minimize these delays by consolidating bus stops, promoting smart-card based fare media, utilizing back-door-only policies for alightings and front-door-only policies for boardings, using low floor buses, and requiring fare payment at the ends of trips. Most BRT routes integrate several of these characteristics in order to reduce running time, increase amenity values, and decrease user cost relative to regular bus service.

Headway adherence may also reduce run time delay created by passenger clustering and overloading (Shalaby and Farhan 2004). However, according to previous research, the amount of time associated with each passenger declines with the increase in passenger activity (Dueker, Kimpel et al. 2004). Overall, reductions in dwell, boarding, and alighting time can lead to changes in mean running time and running time variation. Reductions in mean running time are equally important as reductions in the variation in running time, since average running time affects not only system attractiveness, but the overall costs of providing service as well.

**BRT & ITS Systems**

BRT emulates service quality offered by light rail transit (LRT) at a fraction of the infrastructural cost (Levinson 2003), and it can later be useful as a means to phase in fixed transit infrastructure, such as light rail or heavy rail. Some distinguish BRT as “an incremental investment that may be the precursor to eventual implementation of rail” (Polzin and Baltes 2002, p. 60). Published research speculates that BRT, as a “new” mode of public transportation, has the potential to reduce travel times, attract new riders, and encourage transit-oriented development (Levinson et al. 2002). A Transit Cooperative Research Program report (TCRP 2003, p. 1) defines BRT in the following manner:

> **BRT is a flexible, rubber-tired rapid-transit mode that combines stations, vehicles, services, running ways, and intelligent transportation system (ITS) elements into an integrated system with a strong positive identity that evokes a unique image. BRT applications are designed to be appropriate to the market they serve and their physical surroundings and they can be incrementally implemented in a variety of environments.**

In the United States, interest in BRT is increasing as an alternative to rail transit due to competitive cost and greater flexibility in serving more dispersed origins and destinations in suburban environments. A key feature of BRT is that it provides frequent, fast, reliable, and identifiable service on a free-flowing lane. As Lewis and Williams (1999) and Mogridge (1997) have observed, an improvement in high-capacity transit service reduces travel times on all modes in a congested corridor.

BRT projects should include, at minimum, exclusive rights-of-way on at least a major part of the corridor. In addition, BRT should incorporate the following attributes:

- Priority at intersections: Queue jumpers and other transit priority measures at intersections can reduce transit travel time.
• Signal priority: BRT buses should receive preferential treatment at signalized intersections to reduce travel time.
• Improved passenger boarding facilities: BRT stations should have permanence and substance. Stations should also be integrated into commercial developments and neighborhoods wherever possible.
• Real-time information: The availability of reliable information regarding a system’s travel times is a valuable resource for its users. Real-time information obtained through the use of an automatic vehicle location system can be available to riders in a variety of formats: over the internet, on information kiosks at stations/bus stops, or over information networks.
• Coordination with land-use planning: BRT system design and land-use planning should be coordinated to provide high-quality transit service in proximity of high-intensity land uses.
• Limited stations: Station spacing is lengthened to reduce travel time.
• Prepaid fares: Elimination of onboard fare collection reduces dwell time at stations.
• Level boarding: Designing the passenger boarding area at the same height as the bus reduces dwell time at stations and provides easy access for all users.
• Unique vehicles: BRT vehicles should be designed to meet the functional requirements of the BRT systems. The BRT system should endeavor to develop a unique identity whereby the look of its vehicles supports the overall image of the operation.
• Direct routing: Simple, easy-to-understand route structures with termini at major generators.

Regardless of what method is used, ITS can play an important role in simplifying the problem of optimizing running times. Variations in running time associated with signalized intersections are being partially addressed by transit signal priority (TSP), which is a strategy mentioned in several studies that focused on transit service reliability and running time (Sterman and Schofer 1976; Levinson 1983). The most recent of these studies examined trip-level data collected from TriMet’s Bus Dispatch System and found that TSP’s impact on a variety of transit performance measures, including running time and OTP, are not consistent across routes and time periods, nor are they consistent across various performance measures. The authors believe that benefits of TSP will accrue only as the result of extensive evaluation and adjustment after initial deployment and that an ongoing performance monitoring and adjustment program should be implemented to maximize TSP benefits.
The goals of this research are two-fold: to evaluate potential passenger demand for the proposed Cedar Avenue BRT corridor and to develop an innovative methodology for estimating running times of new transit services using data collected with handheld GPS units. The original scope of this project focused on developing these estimations based on detailed ITS data collected by Metro Transit, the primary transit service provider in the Twin Cities Metropolitan Area. However, with the transition of the project to focus on a corridor outside of Metro Transit’s service area, this scope had to be adjusted to create estimations using the more limited data available through the Minnesota Valley Transit Authority (MVTA). MVTA is a relatively small suburban transit service provider whose data collection is currently limited to semi-annual manual passenger counts and several TrackStick brand GPS units that record the locations of select buses. As a result, the research team had to develop new methodologies for estimating running times and passenger demands along this corridor using handheld GPS units and manual passenger counts. The methodology and analysis sections of this report will detail the estimations created using this more limited dataset, while the recommendations section will outline how more detailed data from ITS systems such as automatic vehicle locators and passenger counters could be incorporated to refine these estimations in future research.

**Demand Data**

To evaluate potential passenger demand for the Cedar Avenue BRT, the research team utilized several existing datasets available through the US Census and the Metropolitan Council. Planned land uses around the corridor were obtained from a GIS dataset produced by the Metropolitan Council. This dataset is based on the compiled comprehensive plans of municipalities in the Twin Cities area.

Although it is somewhat outdated, the 2000 Census remains the best source of population data at the fine scale (block level) that is necessary for evaluating transit station service areas. Information about the number of individuals living and working in BRT station service areas was obtained from the Longitudinal Employment – Housing Dynamics (LEHD) dataset. LEHD is a collaborative program between states and the U.S. Census Bureau that combines state administrative data on employers and employees with census data. LEHD data provides detailed information about employment and commuting patterns that is increasingly being used in transportation planning applications.

Recent manual passenger counts conducted by MVTA staff were also used to estimate current passenger activity patterns along the BRT corridor. The most recent passenger count for one of the studied routes, Route 442, was perceived by MVTA staff to be out of date, so students were recruited to conduct manual passenger counts on this route.

**Travel Time Data**

To determine current transit travel times in the study area, the research team collected travel time data from two MVTA bus routes serving the Cedar Avenue corridor: Routes 442 and 444, shown in Figure 1. Route 442 is a commuter route that runs south along Cedar Avenue/Highway 77 from the Mall of America transit station to the Apple Valley park and ride station. Of all of the
Figure 1. Studied Routes
existing MVTA bus routes, Route 442 most closely resembles the service that will be provided by the Cedar Avenue BRT. Route 444 is also primarily a commuter route running south along Cedar Avenue/ Highway 77 from the Mall of America transit station. However, after crossing the Minnesota River, Route 444 turns westward and travels along Highway 13 and several residential streets to the Burnsville park and ride station. Route 444 was chosen for data collection in order to determine if the relationship between car and bus travel times differs on freeways, arterials, and local streets.

Travel time data for buses on these routes was collected using QStarz brand GPS data loggers provided by the research team and several TrackStick brand GPS units owned by MVTA. MVTA’s existing GPS units were programmed to take a data point at regular time intervals - approximately every seven seconds - so the research team programmed the QStarz units to record points at the same interval. The research team collected data from buses running on Route 444 during the month of October 2007. Due to contract issues, data collection on Route 442 was delayed until the following spring. The research team collected data from buses running on this route during the months of March and April 2008. During the fall data collection period no major weather issues were present that might have an effect on travel time. Data from spring days with inclement weather (i.e., snow storms) were removed from the analysis.

Travel time data for private vehicles on Routes 442 and 444 was collected during the same time periods using probe vehicles equipped with QStarz GPS units. These GPS units were also programmed to record data points every seven seconds. The research team recruited student volunteers to drive their personal vehicles along each studied transit route. Each student was provided with a bus schedule and map of the route, driving directions, and a GPS unit. They were instructed to leave the first station on the route at the same time as a bus and to drive at the speed of traffic until they reached the end of the route.

MVTA staff downloaded data from the GPS units at the end of each week and the research team then imported the data into GIS software for cleaning. Appendix B of this report includes the step-by-step instructions created by the research team for preparing data collected from handheld GPS units for analysis. In order to establish the relationship between travel times for buses and private vehicles in the study area, each bus trip was matched with a probe vehicle trip that departed at approximately the same time. After cleaning and matching the car and bus data, this data collection effort resulted in a sample of 286 matched trips (143 probe vehicle trips matched to 143 bus trips). This sample represents 130 matched trips on Route 442 and 156 matched trips on Route 444. These trips were distributed throughout the day during AM, PM, and off peak periods.

Using this data, it is possible to determine travel times along transit routes. Unfortunately, it is not possible to accurately determine when buses make stops to serve passengers. Many of the stops along Routes 442 and 444 are located on the nearside of signalized or high traffic intersections. Due to this combination of stop placement and the small amount of passenger activity at most stops (one passenger boarding or alighting at non-park and ride stops) it is not possible to distinguish actual passenger stops from regular traffic stops.
RESEARCH METHODOLOGY

As previously stated, the goals of this research are two-fold: to evaluate potential passenger demand for the proposed Cedar Avenue BRT corridor and to develop an innovative methodology for estimating running times of new transit services. The analysis presented in this paper is based upon manual passenger counts on existing transit service in the area, location data collected using handheld GPS units onboard buses and probe vehicles, and supplementary datasets available through the US Census and Metropolitan Council. This section describes the units of analysis and research methodologies used.

Demand Methodology

In order to evaluate potential passenger demand the research team examined employment, commute, and land use patterns for the station areas served by the proposed Cedar Avenue BRT corridor. For this analysis, station service areas were defined as areas within one third of a mile of a proposed BRT station or within two and one half miles of a proposed BRT park and ride station. These figures are derived from previous studies of distance decay for transit service and the Metropolitan Council model, which states that 50% of park and ride demand comes from within 2 ½ miles of a park and ride site (Kimpel et al., 2007; El-Geneidy et al., 2006; URS, 2005). For land use analyses, a straight-line distance buffer was used; for analyses of employment and demographic data, census blocks whose borders are within this buffer were used. Figure 2 shows the proposed locations of BRT stations, park and rides, and their service areas. Analyses of all BRT station service areas include data from 134 census blocks. Analyses including the larger service areas of BRT park and rides utilize data from 1,327 census blocks. A detailed methodology for using LEHD data to evaluate commuting patterns for transit station service areas is included in Appendix C.
Figure 2. Cedar Avenue BRT Stations and Service Areas
Travel Time Methodology

In order to determine current travel times along the proposed BRT corridor and examine the relationship between travel times for personal vehicles and buses, the research team used two levels of analysis. This report first presents a comparison of travel times for different vehicle types along the Routes 442 and 444 as a whole. It then presents a comparison of travel times for different vehicle types along smaller route segments. Routes 442 and 444 provide service to a variety of areas and travel along different types of roads. In order to evaluate the impact of these different route characteristics on bus and private vehicle travel time, the research team divided the two routes into smaller segments with similar attributes (i.e., speed, travel direction, road classification, etc.) for analysis. Figure 3 illustrates these segments.

![Route 442 & 444 Analysis Segments](image)

Figure 3. Route 442 & 444 Analysis Segments

Using travel time data for the routes and the analysis segments, the research team conducted basic statistical analyses to determine travel time patterns. We also used paired t-tests to examine the relationship between car and bus travel times. Using only the data for the
analysis segments, the research team estimated two different multivariate regression models to determine the influence of various route characteristics on travel time for both buses and private vehicles. The specifications of the models are shown below:

(1) \[ \text{Travel Time} = f \text{(northbound, AM, PM, length, freeway, vehicle, signals, stop signs, bus stops, ramp meters)} \]

(2) \[ \text{Natural Log of Difference between Car and Bus Travel Time} = f \text{(northbound, AM, PM, length, freeway, county road, signals, bus stops, meters, route)} \]

The first model examines the factors contributing to travel time for probe vehicles and buses along analysis segments. The covariates in the regressions represent the most theoretically relevant variables included in empirical studies of this type. A dummy variable for whether each vehicle is a bus or probe is included in this model to help determine the difference in travel time due simply to difference in vehicle types. Several variables such as number of traffic signals and bus stops are also included to determine the impact of different route characteristics that may change with implementation of BRT and ITS technologies on travel time. Travel time is expected to be less for private vehicles relative to buses. Travel time is also expected to be less for vehicles traveling on freeway segments relative to vehicles traveling on arterials or residential streets. It is expected to increase with the number of possible stops in a segment, number of traffic signals, number of stop signs, and length of the segment. Vehicles traveling during AM or PM peak hours are expected to have longer travel times relative to vehicles traveling during off peak hours.

The second model evaluates the impact of different route characteristics on the difference between travel time for buses and private vehicles. The difference in travel time equals the travel time for a private vehicle along a segment minus the travel time for a bus traveling along the same segment at the same time of day. The dependent variable for this model is the natural log of the difference in travel times. As a result, the coefficients in this model can be interpreted as the percent change in the difference in travel times that results from a one-unit increase in the independent variable. For this model, the research team hypothesizes that the same relationships exist with the independent variables, with the exception that the AM and PM peak variables may have negative coefficients because buses may use shoulder lanes in some areas to bypass congested traffic. If the numbers of bus stops and traffic signals have significant positive coefficients in both of these models, it is an indication that providing BRT service with consolidated stops and ITS improvements such as signal priority will lead to significant travel time savings. Table 2 describes each of the dependent and independent variables used in the models.
<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Travel Time</td>
<td>The travel time along an analysis segment (see Figure 2)</td>
</tr>
<tr>
<td>LN Difference Travel Time</td>
<td>The natural log of the difference between travel times for a private vehicle and bus traveling on the same analysis segment during the same time of day.</td>
</tr>
<tr>
<td>Northbound (Traveling Towards Downtown)</td>
<td>A dummy variable that equals one if the car or bus is traveling northbound (towards downtown Minneapolis).</td>
</tr>
<tr>
<td>AM Peak</td>
<td>A dummy variable that equals one if the observed car or bus trip started during the AM peak.</td>
</tr>
<tr>
<td>PM Peak</td>
<td>A dummy variable that equals one if the observed car or bus trip started during the PM peak.</td>
</tr>
<tr>
<td>Length of Segment</td>
<td>The length of the analysis segment in kilometers.</td>
</tr>
<tr>
<td>Freeway</td>
<td>A dummy variable that equals one if the car or bus is traveling on a freeway segment (no stops and a speed limit of 60 mph).</td>
</tr>
<tr>
<td>County Road</td>
<td>A dummy variable that equals one if the car or bus is traveling on an arterial or county road segment (signalized stops and a speed limit of 40 mph)</td>
</tr>
<tr>
<td>Vehicle</td>
<td>A dummy variable that equals one if the observed vehicle is a car.</td>
</tr>
<tr>
<td># of Traffic Signals</td>
<td>The number of traffic signals located on the analysis segment.</td>
</tr>
<tr>
<td># of Stop Signs</td>
<td>The number of stop signs located on the analysis segment.</td>
</tr>
<tr>
<td># of Bus Stops</td>
<td>The number of bus stops located on the analysis segment. This variable includes all possible bus stops, not the number of stops actually made.</td>
</tr>
<tr>
<td># of Ramp Meters</td>
<td>The number of active ramp meters located on the analysis segment. This variable is equal to zero for all off peak observations.</td>
</tr>
<tr>
<td>Route</td>
<td>A dummy variable that equals one if the observed trip is along the Route 442.</td>
</tr>
</tbody>
</table>
The benefits of BRT include express service and increased amenity value at a lower cost and with more flexibility than rail transit. However, the success of the Cedar Avenue BRT depends largely on how well it serves commuters in proposed station service areas and the number of area residents and workers that it can encourage to switch modes. As mentioned previously, for this analysis station service areas are defined as areas within one third mile of a proposed BRT station or within two and one half miles of a proposed BRT park and ride station. The following section of this report examines land use, employment, and commuting patterns in proposed Cedar Avenue Busway station service areas and how they may influence passenger demand for BRT service.

**Land Use Patterns**

The existing and proposed land uses surrounding the Cedar Avenue Busway differ from stop to stop. Figure 4 illustrates the planned land uses that will surround the Cedar Avenue Busway based on the comprehensive plans of the cities the corridor will pass through. The area is currently and, according to current comprehensive planning efforts, will continue to be characterized by predominantly single family residential, agricultural, and recreational land uses with several nodes of commercial and industrial uses. Figure 5 shows the planned land uses in the service areas of each proposed BRT station.
Figure 4. Planned Land Uses around the Cedar Avenue Busway
The Mall of America (MOA) Transit Center at the northern end of the Cedar Avenue BRT and the proposed 147th Street station in Apple Valley are the commercial centers along the corridor. The Cedar Grove and Cliff Road stations, located across the Minnesota River to the south of the MOA station, have very mixed uses in their service areas. Although these stations will be surrounded by a significant amount of single and multiple family housing, a large portion of their service areas will be taken up by transportation related land uses such as park and ride lots and highway and rail rights of way. The Palomino Hills and 140th Street stations, located to the north of the 147th Street commercial center, are surrounded predominantly by single family housing. To the south of the 147th Street station, on the other hand, the Apple Valley Transit Center and 180th Street stations will be surrounded primarily by multifamily housing and some commercial uses. Interestingly, despite the proposed placement of a BRT station at 195th Street, planned land uses available through the Metropolitan Council show that this station will continue to be surrounded solely by agricultural uses. The 215th Street park and ride station, on the other hand, is predicted to experience some additional development as the industrial center at the southern end of the BRT line.

This combination of land uses shows that the Cedar Avenue BRT will provide a transit connection for the residents of Apple Valley and Lakeville and may offer an alternative mode for some commuters. The areas south of the Apple Valley Transit Center that will be served by this corridor are not currently served by transit, which presents an opportunity; however, the low-
density land uses around some stations (especially 195th Street) could be a threat. The number of commuters that could be served by the Cedar Avenue BRT depends in large part on the employment patterns of station area residents, which the remainder of this section will address.

**Population**

According to the 2000 U.S. Census, census blocks within proposed BRT station service areas had a total population of 15,723. If the residents of census blocks within 2.5 miles of proposed BRT park and ride stations are included, this figure jumps to 184,468. Figure 6 shows the total population, number of workers, and number of jobs in each station’s service area. (Due to overlap in some stations’ service areas these figures add up to more than 100 percent.) The majority of these residents live in Eagan or Apple Valley near the Cliff Road, Palamino Hills, 147th Street, and Apple Valley Transit Center stations.

![Figure 6. Population, Workers, and Jobs in BRT Station Service Areas](chart)

**Data Source:** US Census 2000, Longitudinal Employment and Housing Dynamics 2003

**Workers**

According to the most recent LEHD data available from the Census Bureau, 9,084 residents of BRT station service areas were employed in 2003. Three quarters of these workers lived in census blocks surrounding the Cliff Road, Palamino Hills, 140th Street, and Apple Valley Transit Center stations. As Figure 6 shows, the Apple Valley Transit Center has the largest total population (3,074) and the Palomino Hills station has the largest employed population (1,828) in
its individual service area. With the exception of the 147th Street station, which is surrounded by a large number of senior housing units, the percentage of the population that is employed in BRT station areas is fairly consistent throughout the corridor and is approximately 58%.

Figure 7 shows the total population and number of employed individuals in the immediate one-third mile and larger 2.5 mile service areas of proposed park and ride stations on the Cedar Avenue Busway. By including these park and ride stations the potential number of individuals served by the BRT is increased dramatically. In this larger service area there were 184,468 residents in 2000 and 110,150 workers in 2003. The Palomino Hills park and ride station had the largest total population and number of employed residents in its park and ride service area, followed by the Apple Valley Transit Center. The 215th Street park and ride station, on the other hand, had the smallest total population and number of workers, but almost all of the riders who use this station will come from the larger park and ride service area.

![Figure 7. Population and Workers in BRT Park and Ride Station Areas](image)

**Figure 7. Population and Workers in BRT Park and Ride Station Areas**

*Data Source: US Census 2000, Longitudinal Employment and Housing Dynamics 2003*

**Jobs**

The number of jobs within BRT stations' service areas can also be derived from the LEHD. In 2003, six of the ten proposed BRT stations had a larger number of jobs than employed residents in their service area. In total, 26,898 jobs were located in census blocks within one-third mile of stations; however, the vast majority of these jobs were located near the Mall of America station. Excluding the Mall of America station, a total of 11,961 jobs were located in the Cedar Avenue
Busway service area. The largest number of jobs (outside of the Mall of America) was located in the commercial center surrounding the 147th Street station.

**Commuting Patterns**

Figure 8 shows the commuteshed for BRT station service areas, or the areas where people who live near proposed BRT stations travel to work. The area around each BRT station that is shaded in gray indicates the study area for this analysis – year 2000 census blocks within one-third mile of a proposed BRT station or within 2.5 miles of a proposed BRT park and ride station. The other colored polygons on the map indicate the number of BRT station area residents that work in (commute to) each census tract.

As Figure 8 shows, businesses in and surrounding the Mall of America and Minneapolis/St. Paul International Airport are by far the largest employers of BRT service area residents. The next largest employment location for BRT service area residents is south of the Minnesota River near the Cedar Grove park and ride, and downtown Minneapolis near the end of the Hiawatha LRT (which BRT riders can easily access by transferring at the MOA transit...
The junction of Interstate 35E and 35W is also a major employment area for BRT residents, but is not within the service area of any BRT stations and is not easily reachable via existing transit connections.

In 2000, 2.4% of residents living within one-third mile of a proposed BRT station used transit as their usual means of traveling to work. In the 2.5 mile park and ride service area, transit also had an average mode share of 2.4% in 2000. BRT service will likely increase the transit mode share in these areas by increasing the viability of transit for commuters, especially those who commute to the Mall of America, Cedar Grove, or downtown Minneapolis areas. The Cedar Avenue Busway can attract a portion of these commuters in particular due to the attractiveness of BRT compared to existing bus service and because these workers’ places of employment are within one-third mile of BRT stations, a distance that most transit users are willing to walk.

Figure 9 shows the number of BRT station area and park and ride area residents who also worked within one-third mile of a proposed BRT station in 2003. Only 75 individuals both lived and worked within one-third mile of a BRT station and all but two of these workers commuted to the Mall of America station area from Apple Valley. Overall, 5,328 workers who lived in the 2.5 mile park and ride service area commuted to work in a job within one-third mile of a BRT station. As discussed previously and illustrated by Figure 9, the majority of these internal commuters work at jobs near the Mall of America or in the commercial center surrounding the proposed 147th Street station. The distribution of internal commuters along the corridor closely reflects the overall distribution of jobs along the corridor (shown in Figure 6).
Another important aspect to consider when measuring the potential impact of the Cedar Avenue Busway is not only where station area residents travel to work, but also where employers in the BRT service area draw their workforce. The area that an employer draws its employees is referred to as the employer’s laborshed. Figure 10 shows the laborshed for employers in the BRT one-third mile service area (shaded in grey on the map). As the map indicates, the majority of the individuals who worked in the BRT service area in 2003 commuted from census tracts within five miles of the corridor. Twenty-two percent of the 26,898 jobs in the BRT service area were held by workers who commuted from the areas marked in red on this map.

Figure 9. Number of BRT Service Area Residents Working Near Proposed BRT Stations

*Data Source: US Census 2000, Local Employment and Housing Dynamics 2003*
Figure 10. Laborshed for Cedar Avenue BRT Station Service Areas
TRAVEL TIME ANALYSIS

The goal of this research is both to evaluate conditions effecting passenger demand for the proposed Cedar Avenue BRT corridor and to develop a methodology for estimating BRT travel times using GPS data collected by probe vehicles. In order to determine current travel times along the proposed BRT corridor and examine the relationship between travel times for personal vehicles and buses, the research team used two levels of analysis: the bus route and route segment level. The research team created route segments by dividing Routes 442 and 444 into smaller sections with similar attributes (i.e., speed, travel direction, road classification, etc.) in order to determine the influence of these attributes on travel time. (See Figure 3 for a map of analysis segments.) This section presents the results of the travel time analyses.

Route Travel Time Analysis

Using travel time data for the routes and the analysis segments, the research team conducted basic statistical analyses to determine travel time patterns. Figures 11 - 14 show the travel time distributions for buses and private vehicles on Routes 442 and 444. For the 130 matched trips on Route 442, travel time for buses ranged from 21 to 42 minutes with a median value of 24.6 minutes. Travel time for private vehicles on this route ranged from 17 to 26 minutes with a median value of 21 minutes. The standard deviation of personal vehicle travel times is, not surprisingly, smaller than the standard deviation for buses. The median observed travel time for buses is 3.6 minutes longer than that for personal vehicles. The median observed travel time for personal vehicles is equal to the minimum observed travel time for buses.
Figure 11. Route 442 Bus Travel Time Distribution

Figure 12. Route 442 Private Vehicle Travel Time Distribution
For the 156 matched trips on Route 444, travel time for buses ranged from 17 to 27 minutes with a median value of 20.3 minutes. Travel time for private vehicles on this route ranged from 13 to 24 minutes with a median value of 16.8 minutes. The standard deviation of personal vehicle travel times on this route is slightly larger than the standard deviation for buses. However, it is again the case that the median observed travel time for personal vehicles is equal to the minimum observed travel time for buses. The difference between median observed travel times for buses and personal vehicles on this route is almost the same as that found for Route 442. The median travel time for buses on this route is 3.5 minutes longer than that for personal vehicles.

![Route 444 - Buses](image)

Figure 13. Route 444 Bus Travel Time Distribution
Statistical Analysis

Paired T-Tests

After examining the distributions of travel times, the research team used paired t-tests to examine the relationship between car and bus travel times along routes and route segments. Table 3 presents the results of each of the t-test comparisons. Both of the route level comparisons are significant at the 99% level of confidence. At the route level, the mean difference between travel times for buses and private vehicles is 3.98 minutes for Route 442 and 3.59 minutes for Route 444. The difference in bus and car travel times at the route level ranges from 3.08 to 4.87 minutes for Route 442 and from 2.91 to 4.26 minutes for Route 444.

All but three of the t-tests conducted at the route segment level are significant at the 90% level of confidence. Segments 6 and 17 are mainly the first two segments in each route, while segment 13 is part of 2.5 miles along highway 77.
Table 3: Paired T-Test Comparisons

<table>
<thead>
<tr>
<th>Road Type</th>
<th>Mean Difference (minutes)</th>
<th>95% Confidence Interval of the Difference</th>
<th>t</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Route 442</td>
<td>-3.98</td>
<td>-4.87, -3.08</td>
<td>-8.87</td>
<td>.000</td>
</tr>
<tr>
<td>Route 444</td>
<td>-3.59</td>
<td>-4.26, -2.91</td>
<td>-10.56</td>
<td>.000</td>
</tr>
<tr>
<td>All Segments</td>
<td>-0.52</td>
<td>-0.59, -0.45</td>
<td>-13.95</td>
<td>.000</td>
</tr>
<tr>
<td>Segment 1</td>
<td>Local Street -0.74</td>
<td>-1.13, -0.35</td>
<td>-3.81</td>
<td>.000</td>
</tr>
<tr>
<td>Segment 2</td>
<td>Freeway -0.91</td>
<td>-1.45, -0.36</td>
<td>-3.32</td>
<td>.002</td>
</tr>
<tr>
<td>Segment 3</td>
<td>Local Street -0.40</td>
<td>-0.82, 0.02</td>
<td>-1.95</td>
<td>.059</td>
</tr>
<tr>
<td>Segment 4</td>
<td>Arterial -0.48</td>
<td>-0.60, -0.36</td>
<td>-8.33</td>
<td>.000</td>
</tr>
<tr>
<td>Segment 5</td>
<td>Local Street -0.46</td>
<td>-0.75, -0.16</td>
<td>-3.06</td>
<td>.003</td>
</tr>
<tr>
<td>Segment 6</td>
<td>Arterial -0.38</td>
<td>-0.93, 0.17</td>
<td>-1.40</td>
<td>.171</td>
</tr>
<tr>
<td>Segment 7</td>
<td>Arterial -0.60</td>
<td>-0.92, -0.28</td>
<td>-3.85</td>
<td>.001</td>
</tr>
<tr>
<td>Segment 8</td>
<td>Local Street -0.89</td>
<td>-1.13, -0.65</td>
<td>-7.43</td>
<td>.000</td>
</tr>
<tr>
<td>Segment 9</td>
<td>Arterial -0.22</td>
<td>-0.37, -0.07</td>
<td>-2.93</td>
<td>.007</td>
</tr>
<tr>
<td>Segment 10</td>
<td>Local Street -0.59</td>
<td>-0.88, -0.31</td>
<td>-4.30</td>
<td>.000</td>
</tr>
<tr>
<td>Segment 11</td>
<td>Arterial -0.08</td>
<td>-0.14, -0.03</td>
<td>-3.11</td>
<td>.003</td>
</tr>
<tr>
<td>Segment 12</td>
<td>Local Street -0.35</td>
<td>-0.68, -0.02</td>
<td>-2.10</td>
<td>.040</td>
</tr>
<tr>
<td>Segment 13</td>
<td>Freeway -0.05</td>
<td>-0.22, 0.13</td>
<td>-0.55</td>
<td>.586</td>
</tr>
<tr>
<td>Segment 14</td>
<td>Arterial -1.53</td>
<td>-1.83, -1.12</td>
<td>-10.19</td>
<td>.000</td>
</tr>
<tr>
<td>Segment 15</td>
<td>Local Street -0.85</td>
<td>-1.05, -0.66</td>
<td>-8.57</td>
<td>.000</td>
</tr>
<tr>
<td>Segment 16</td>
<td>Local Street -0.35</td>
<td>-0.56, -0.13</td>
<td>-3.19</td>
<td>.002</td>
</tr>
<tr>
<td>Segment 17</td>
<td>Arterial -0.11</td>
<td>-0.32, 0.10</td>
<td>-1.029</td>
<td>.307</td>
</tr>
<tr>
<td>Segment 18</td>
<td>Local Street 0.23</td>
<td>-0.03, 0.48</td>
<td>1.79</td>
<td>.080</td>
</tr>
<tr>
<td>Segment 19</td>
<td>Local Street -0.83</td>
<td>-1.18, -0.48</td>
<td>-4.83</td>
<td>.000</td>
</tr>
</tbody>
</table>

Regression Models

Using only the data for the analysis segments, the research team estimated two multivariate regression models to determine the influence of various route characteristics on travel time for both buses and private vehicles. The first model examines the factors contributing to travel time for probe vehicles and buses along analysis segments. In this model observed travel time (in seconds) along a route segment is used as the dependent variable. Table 4 shows the output for this model. Note that statistically significant variables are in bold.
### Table 4: Travel Time Model

<table>
<thead>
<tr>
<th>Independent Variables</th>
<th>B</th>
<th>t</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Constant)</td>
<td>20.06</td>
<td>4.77  ***</td>
</tr>
<tr>
<td>Traveling towards Downtown</td>
<td>-10.75</td>
<td>-4.22 ***</td>
</tr>
<tr>
<td>AM Peak</td>
<td>11.26</td>
<td>3.51  ***</td>
</tr>
<tr>
<td>PM Peak</td>
<td>17.02</td>
<td>5.22  ***</td>
</tr>
<tr>
<td>Length of Segment</td>
<td>37.51</td>
<td>26.24 ***</td>
</tr>
<tr>
<td>Traveling on Freeway</td>
<td>-11.04</td>
<td>-1.15</td>
</tr>
<tr>
<td>Vehicle is a Car</td>
<td>-30.27</td>
<td>-12.28 ***</td>
</tr>
<tr>
<td># of Traffic Signals</td>
<td>25.85</td>
<td>25.25 ***</td>
</tr>
<tr>
<td># of Stop Signs</td>
<td>15.80</td>
<td>7.42  ***</td>
</tr>
<tr>
<td># of Possible Bus Stops</td>
<td>8.70</td>
<td>13.05 ***</td>
</tr>
<tr>
<td># of Ramp Meters</td>
<td>-6.42</td>
<td>-1.66  *</td>
</tr>
</tbody>
</table>

Adjusted R-square: 0.69  
N: 2,138  
Dependent Variable: Segment Travel Time (seconds)

* Significant at the 90% level; *** significant at the 99% level

This model has an R-square of 0.69 with all variables having a statistically significant effect on travel time except for the freeway variable. In addition, all variables in the model have the expected sign and follow transit operation theory. For example, the length of the segment is found to be statistically significant with a positive effect on travel time. Travel time increases by 37.51 seconds for each kilometer a vehicle must travel. AM and PM peak road conditions also have a positive effect on travel time. Relative to travel times during off peak hours, travel time along each segment increase by 11.26 seconds during the AM peak and 17.02 seconds during the PM peak, holding all else constant.

As expected, traffic signals, stop signs, and bus stops all have positive coefficients in this model. For each traffic signal on a route segment travel time increases by 25.85 seconds. There are currently eight traffic signals located on the Cedar Avenue corridor that the BRT will pass through. If transit signal priority (TSP) is provided at these lights for BRT, this would lead to a 3.4 minute travel time savings. Each stop sign on a route segment increases travel time by 15.8 seconds. By running straight down the Cedar Avenue corridor and avoiding residential areas with stop signs currently served by Route 442, the BRT will gain additional travel time savings. Route 442 currently travels through four stop signs, which add just over a minute to the route’s travel time. Similarly, each possible bus stop along a route segment increases travel time by 8.7 seconds, whether the bus actually stops to serve passengers or not (Unfortunately, using the data collected by handheld GPS units taking points at regular time (as opposed to distance) intervals,
it was not possible for the research team to determine when buses actually stopped to serve passengers. In future research, the number of actual stops made as well as the number of possible stops should be included as variables in this model.) By consolidating bus stops and cutting the number of possible stops along Cedar Avenue in half, the BRT will achieve more travel time reductions. The 20 possible stops along Route 442 currently account for 2.7 minutes of each bus’s travel time. The Cedar Avenue BRT, alternatively, will serve a longer segment of the corridor (MOA transit center to Lakeville) with only 10 possible stops, adding only 1.35 minutes to each bus’s travel time.

Variables in this model with a negative effect on travel time are direction of travel, number of ramp meters, traveling on the freeway, and traveling in a car. All else held constant, northbound trips (heading towards downtown Minneapolis) have a 10.75 second shorter travel time on each route segment. Ramp meters have a minor impact on travel times during rush hours. Each ramp meter reduces travel time by 6.42 seconds. As expected, type of vehicle has the largest negative impact on travel time. On each route segment private vehicles have a 30.27 second shorter travel time than buses. Route 442 is divided into eight segments southbound and nine segments northbound, which translates into a four minute shorter travel time for cars traveling south and 4.5 minute shorter travel time for cars traveling north relative to buses, all else being equal.

The second model evaluates the impact of different route characteristics on the difference between travel time for buses and private vehicles. The difference in travel time equals the travel time for a private vehicle along a segment minus the travel time for a bus traveling along the same segment at the same time of day. The dependent variable for this model is the natural log of the difference in travel times. As a result, the coefficients in this model can be interpreted as the percent change in the difference in travel times that results from a one-unit increase in the independent variable. Table 5 shows the outputs of this model.

This model has an R-square of 0.18 with the majority of variables having a statistically significant impact on the relationship between bus and car travel times. Again, the variables in this model have the expected signs and follow transit operation theory. The difference between car and bus travel times is 18% greater during the AM peak hours relative to off peak hours, all else held constant. The difference between car and bus travel times is greater on longer route segments. For each additional kilometer traveled, the difference between car and bus travel times increases by 16%. Traffic signals and bus stops, not surprisingly, also have a positive impact on the difference between car and bus travel times. Each traffic signal increases the travel time difference by 19% due to buses’ slower acceleration time and other factors. The number of possible bus stops has a smaller impact on travel time difference than expected. For each possible stop the difference in travel time increases by 3%, whether the bus stops or not. The small magnitude of this variable could be because of the large number of possible stops and small number of actual stops being made on the studied routes. Alternatively, some of the impact of stops may be attributed to traffic signals in this model due to the prevalence of stops located on the nearside of signalized intersections along the Cedar corridor. Regardless, these results show that consolidating bus stops and implementing TSP as part of the Cedar Avenue BRT corridor will help to reduce the travel time disparity between buses and private vehicles in the region and increase the attractiveness of transit.
Several factors have a significant negative impact on the difference between travel times for private vehicles and buses. The difference between car and bus travel times is 21% less for northbound trips heading towards downtown Minneapolis. The largest contributor to reducing travel time differences, however, is traveling on the freeway. On freeway route segments buses actually had a shorter travel time than personal vehicles on average, all else being equal. This is likely due to the fact that buses can bypass congested traffic and ramp queues on freeway segments of the Cedar Avenue corridor by using bus only shoulder lanes. BRT will implement dedicated shoulder lanes and freeway like conditions for buses along the entire Cedar Avenue corridor, meaning that it will increase the attractiveness of transit by minimizing travel time advantages of personal vehicles over transit. As was the case with the Hiawatha LRT corridor in Minneapolis, growing congestion and transit improvements may eliminate the transit travel time disparity all together, causing mean transit travel times to be lower than mean personal vehicle travel times.
CONCLUSIONS/RECOMMENDATIONS

The analysis presented in this report highlights several issues related to the Cedar Avenue Busway in particular and to BRT/transit planning in general. This research report has evaluated conditions along the Cedar Avenue corridor that will influence potential passenger demand for the line. It has also outlined an innovative approach for estimating travel time for new transit lines based on GPS data collected by probe vehicles. The statistical analyses presented in this report were conducted at two levels: the route level and the route segment level. The research team’s analysis of route level travel time patterns shows that on the Cedar Avenue corridor buses have greater variation in their travel times than vehicles. However, for both of the studied routes the median travel time for private vehicles was equal to the minimum travel time for buses. The difference between median car and bus travel times for both routes was approximately 3.5 minutes.

The analysis of route segment level data provides a more detailed understanding of the relationship between vehicle type, route characteristics, and travel time. While personal vehicles have an inherent travel time advantage over buses under existing conditions on the Cedar Avenue corridor (and most major arterials), our analysis shows that altering route characteristics can reduce overall travel time and minimize the travel time disparity between buses and cars. In particular, the models presented in this report lend support to stop consolidation and implementation of transit signal priority along the Cedar Avenue corridor. Providing transit signal priority at the eight traffic signals currently located on the corridor would reduce bus travel time by four minutes for southbound trips and 4.5 minutes for northbound trips. This strategy would also eliminate the travel time advantage of private vehicles over buses on the corridor, according to our second model. Reducing the number of possible bus stops between the Mall of America transit station and Apple Valley park and ride station from 20 to seven, will remove an additional 1.7 minutes from the current bus travel time along this section of the corridor. Finally, by running straight down the Cedar Avenue corridor and avoiding smaller, local streets, the BRT will save an additional one minute in travel time that is currently spend at stop signs. In addition to this travel time savings, remaining on the main corridor where there are freeway-like conditions will help to reduce the difference between travel time for BRT buses and personal vehicles even more.

Route 442 buses currently take approximately 25 minutes to travel from the Mall of America transit station to the Apple Valley park & ride station. The median travel time for personal vehicles along this route is 3.5 minutes shorter than that for buses. If the travel time savings resulting from stop consolidation, transit signal priority, and stop sign elimination are factored into this figure, travel time along the section of the Cedar Avenue corridor currently served by Route 442 would decrease to just over 18 minutes. Under these conditions, travel time via BRT would be approximately 2.5 minutes shorter than median travel time via personal vehicle. This travel time would increase the amenity value of the Cedar Avenue Busway, attract increased ridership, and help to ensure the success of this transit line.

In conclusion, it should be noted that the analyses presented in this report are based on a very limited travel time dataset collected using handheld GPS units. When this project began it was focused on the Bottineau Boulevard BRT corridor in the northwest Twin Cities metropolitan area and was designed to use the detailed data available from Metro Transit’s automatic vehicle locator (AVL) and automatic passenger counter (APC) systems. However, with the change of
Bottineau Boulevard from a BRT to LRT candidate, this project was adapted to focus on the Cedar Avenue corridor, and a new methodology was developed to predict travel time for a transit provider with no existing ITS data collection systems. All of the data included in the travel time analyses presented in this report are derived from handheld GPS data. Due to the placement of many MVTA bus stops on the nearside of signalized intersections and the programming of our GPS units to record points every seven seconds, the research team was not able to determine when actual passenger stops were being made. Also, budgetary restrictions prevented MVTA or the research team from being able to collect passenger counts for the entire study period.

Future studies based on handheld GPS data should program their units to record points based on fine grained distance intervals (i.e., 50 feet) in order to make stop identification more possible. Future research should also budget for passenger counts for the entire study period. The number of possible and actual stops should be included in future versions the models presented in this report to obtain a more accurate estimation of the amount of travel time savings achieved through stop consolidation. The number of passenger boardings and alightings as well as the square of these variables should also be included in future models in order to determine the impact of increased passenger demand on travel time. Other data that should be included in these models and may be available from transit agencies with more advanced ITS systems include: smart card use, lift use, bus-only shoulder use, etc.
REFERENCES


APPENDIX A: GPS DATA COLLECTION INSTRUCTIONS
Route 444 Driving Directions

Remember to record your mileage before you start driving!!

Using the GPS unit:
- Before you begin driving, slide the bar on the left side of the GPS unit all the way up so that it is in the “LOG” position.
- The orange light on the top of the unit (near the red button) will turn on and blink.
- Set the GPS unit on the dashboard of your car near the windshield.
- Drive the 444 route several times.
- When you’re done driving, slide the bar on the left side of the GPS unit back down to the “OFF” position.

Getting to the Mall of America Transit Station entrance:

From Minneapolis:
- Take I-35W or Cedar Ave. (Highway 77) south.
- Take exit 9A to I-494 east.
- From 494, take the exit 2A to 24th Ave S.
- Keep right and follow 24th Ave. S. several blocks south.
- Turn right on Killebrew Dr.

Driving Route 444 Southbound (Mall of America to Burnsville Transit Station):
- Drive west on Killebrew Dr. and take the ramp to Cedar Ave. / Highway 77 south.
- Follow Cedar Ave. / Hwy 77 for 3.5 miles south.
- Turn right on Difflrey Rd.
- Turn left on Highway 13. Follow Highway 13 for 1.5 miles.
- Turn left on County Road 11. Drive 2 blocks.
- Turn right on 122nd St. E. Drive 2 blocks and follow the road as it curves.
- Turn left on Parkwood Dr. (Not Parkwood Pl. – that’s a dead end!) Drive 2 blocks.
- Turn right on Burnsville Pkwy E. Go 1 block.
- Turn right on Portland Ave. Drive 2 blocks.
- Turn left on Highway 13.
- Turn right on Nicollet Ave.
- Turn right into the Burnsville Transit Center lot.
Driving Route 444 Northbound (Burnsville Transit Station to Mall of America):

- Drive straight towards the Transit Center Building, drive around the drop off lane in front of the building, and drive back out of the lot the way you came in.

- **Turn left** on Nicollet Ave.

- **Turn left** on Highway 13. Drive 2 blocks.

- **Turn right** on Portland Ave. Drive 2 blocks.

- **Turn left** on Burnsville Pkwy E. Drive 1 block.

- **Turn left** on Parkwood Dr. Drive 2 blocks.

- **Turn right** on 122\(^{nd}\) St. E. (This is the road before the stoplight.) Drive 2 blocks and follow the road as it curves.

- **Turn left** on County Road 11. Drive 2 blocks.

- **Turn right** on Highway 13. Drive 1.5 miles.

- **Turn right** on Diffley Rd.

- **Turn left** on Highway 77 North/ Cedar Ave. Drive 3.5 miles north.

- Take the Lindau Lane exit. Drive straight for 2 blocks.

- **Turn right** on 24\(^{th}\) Ave. S.

- **Turn right** on Killebrew Dr.

*Remember to record your mileage when you’re done driving*
Route 442 Driving Directions

*Remember to record your mileage before you start driving!!*

Using the GPS unit:
- Before you begin driving, slide the bar on the left side of the GPS unit all the way up so that it is in the “LOG” position.
- The orange light on the top of the unit (near the red button) will turn on and blink.
- Set the GPS unit on the dashboard of your car near the windshield.
- Drive the 442 route several times.
- When you’re done driving, slide the bar on the left side of the GPS unit back down to the “OFF” position.

Getting to the Mall of America Transit Station entrance:

*From Minneapolis:*
  - Take I-35W or Cedar Ave. (Highway 77) or Hiawatha Ave. south.
  - Take exit 9A to I-494 east (west if you take Hiawatha).
  - From 494, take the exit 2A to 24th Ave S.
  - Keep right and follow 24th Ave. S. several blocks south.
  - Turn right on Killebrew Dr.

Driving Route 442 Southbound (Mall of America to Apple Valley Transit Station):
- Drive west on Killebrew Dr. and take the ramp to Cedar Ave. / Highway 77 south.
- Follow Cedar Ave. / Hwy 77 for 6.6 miles south.
- Take the Palomino Dr/127th St exit
- Turn right at Palomino Dr - 302 ft
- Turn left at Pennock Ave - 0.6 mi
- Turn left at McAndrews Rd - 0.2 mi
- Turn right to merge onto Cedar Ave/CR-23 S - 0.9 mi
- Turn right at 140th St W - 0.3 mi
- Turn left at Pennock Ave - 0.8 mi
- Turn left at 147th St W - 0.3 mi
- Turn right at Cedar Ave - 1.0 mi
- Turn left at 157th St W - 0.1 mi
- Turn left on Gaslight - 0.2 mi
Driving Route 442 Northbound (Apple Valley Transit Station to Mall of America):

- Drive past the Apple Valley Transit Station. **Turn left** onto **155th St**, then **turn right** on **Cedar Ave.** and backtrack along the route the way you came.
- **Turn right** on **Cedar Ave.** – 1.0 mi
- **Turn left** at **147th St W** - 0.3 m
- **Turn right** at **Pennock Ave** - 0.8 mi
- **Turn right** at **140th St W** - 0.3 mi
- **Turn left** onto **Cedar Ave/CR-23 S** - 0.9 mi
- Take the **38 exit**
- **Turn right** at **McAndrews Rd** - 0.2 mi
- **Turn right** at **Pennock Ave** - 0.6 mi
- **Turn right** at **Palomino Dr** - 302 ft
- **Turn left** to merge onto **Cedar Ave/CR-23 S** - 0.9 mi
- Follow **Cedar Ave. / Hwy 77** for 6.6 miles south.
- Take the **Lindau Lane exit**. Drive straight for 2 blocks.
- **Turn right** on **24th Ave. S**.
- **Turn right** on **Killebrew Dr**.

*Remember to record your mileage when you're done driving!*
BUS AND PROBE VEHICLE DATA CLEANING PROCESS

For data from QStarz and Trackstick brand units:
- Import .csv file containing GPS data into ArcGIS
- Add field ‘time_adjust’ and ‘time_text’
- Calculate value of time_adjust = ‘time’+time(18,0,0)
- Convert time to text in ‘time_text’
- Add Longitude2 field
- Calculate value of Longitude2 = Longitude*-1
- Make XY event layer based on fields “latitude” and “longitude2”
- Select features within 20 meters of route
- Export layer as feature class in bus_probe_cleaning.gdb
- Remove “no fix” features
- Add “trip”, “direction”, “matchID”, “vehicle”, “peak”, and “GPS” fields
  o Trip = unique Id for trip from MOA to Burnsville Transit Center
  o Direction = N (to MOA) or S (to Burnsville)
  o matchID = unique ID for pair of bus and probe trips departing at same time in same direction
  o vehicle = BUS or PROBE
  o peak = AM, PM, or OFF
  o GPS = TS or QStarz

For data from MVTA’s Trackstick Units only:
- delete blank lat lon records
- separate date and time fields (time is recorded in CST in .csv output files, time in .tsf files is CST – 6 hours)

Trip matching and additional cleaning:
- Hand select trips from MOA to BTC and assign direction, peak period, and unique tripID
- Identify probe and bus trips running in same direction during same peak period (ideally during same day or approximately same departure time) and assign unique matchID equal to the bus tripID concatenated to the probe tripID
- Add additional fields:
  o CST_Time = time in central standard time zone
  o Speed_mph = speed_km/hr * 0.621371192 - OR- int(left([SPEED],5))*0.621371192
  o Depart = scheduled departure time
  o StopID = SiteID of stop that point is within 100 feet of
  o Road type = ‘hwy’, ‘cord’, or ‘res’
  o Stopped = 1 if bus probably stopped, 0 if didn’t
  o Board = number of passengers who boarded bus (estimated from mvta passenger count)
  o Alight = number of passengers who alighted bus (estimated from MVTA passenger count)

Road type:
- add road type field to route444 shapefile
- classify road sections as hwy, cord, res, or other (areas around Burnsville TC)
- spatial join data points to route 444 shapefile and give points attributes of closest road section (east_route444_type)

Stop locations:
- selected from transit stop shapefile available on datafinder.org
- selected stops with route 444 listed as route and double checked accuracy
- add direction for each stop
- create 100 foot buffer for each stop
- create separate files of east and westbound data points
- project data point files (East_route44_probe2) and spatial join to stop buffers

Create Milemarkers:
- remove points near MOA garage entrance and Burnsville TC (because GPSs take awhile to get good reception again and vehicles can’t take same route as buses)
- create east and west route file for route 444
- locate cleaned points along route (east_444probe_milepost) only include OID in output (mile zero is end closest to MOA)
- join milepost file to type file
- export table (east_route444_final) to analysis GDB

Calculate Travel Time:
- import milemarker tables into analysis GDB
- create “all_bus_data” and “all_probe_data” tables
- remove records where milepost is null
- create separate crosstab queries for probes and buses using direction, peak, and matchID as rows, vehicle as columns, and min and max CST_times as values
- using matchID as join, create bus and “probe triptime” query tables where min_time = starttime, max_time = endtime, triptime = [endtime]-[starttime], TT_seconds = DateDiff(“s”, [starttime],[endtime]), TT_minutes = ([TT_seconds]/60)
- using matchID as join, create “matched_triptime” query table with peak, direction, start time, end time, and TT_minutes for bus and probe in each pair
APPENDIX C: BOTTINEAU BOULEVARD BRT PRELIMINARY ANALYSIS
Estimating Running Time and Demand for a Bus Rapid Transit Corridor

Interim report

July 2007

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Estimating Running Time and Demand for a Bus Rapid Transit Corridor

Introduction

The primary objective of this research is to develop a better understanding of the factors affecting bus transit service demand and travel time. Specifically, this research uses data from a variety of sources to estimate travel time and potential demand for a proposed bus rapid transit (BRT) route along a specific corridor in the Twin Cities region. BRT is similar to regular bus service but differs in terms of its frequency of service and speed. Typical characteristics of BRT routes such as less frequent stop spacing, dedicated lanes, and intelligent transportation systems (ITS) technologies (i.e., signal priority) help to decrease travel time and increase the speed of BRT service relative to regular bus service. More frequent service also means that BRT has the potential to serve more riders and provide a higher quality of service. The increase in transit ridership in the Twin Cities region since the 2004 opening of the Hiawatha light rail line shows that there is potential for implementing BRT service in this region. The findings of this research present a more detailed analysis of the practical potential of a BRT corridor in the Twin Cities region both in terms of running time and demand.

This report summarizes the research team’s work to date on estimating the potential demand for transit service along the studied corridor. In addition, it reports on the methodology being developed to create accurate estimations of running time using Global Positioning System (GPS) units. The report is organized in three main sections. The first section analyzes the proposed BRT corridor and the current land use, employment, and commuting characteristics around station areas. The second section discusses the concept of distance decay and how it can be derived and used in estimating demand for transit service around the corridor. The third section contains a manual on how to use a GPS unit to collect data for travel time estimations.

Employment and Land Use

The Bottineau Boulevard BRT, expected to begin service in 2009, will be the first of a series of planned BRT corridors serving the Twin Cities Metropolitan Area. When completed, the Bottineau BRT will run from downtown Minneapolis along West Broadway Ave. and County Road 81 through Brooklyn Park to Osseo. This route represents the main northwest corridor in the Twin Cities region and an area that is projected to experience a large growth in both jobs and congestion over the next 20 years. The benefits of BRT include express service and increased amenity value at a lower cost and with more flexibility than rail transit. However, the success of the Bottineau BRT depends largely on how well it serves commuters in proposed station service areas and the number of area residents and workers that it can encourage to switch modes.
This report presents employment, commute, and land use data for the station areas served by the proposed Bottineau Boulevard BRT corridor. For this analysis, station service areas are defined as areas within one third of a mile of a proposed BRT station location. For land use analyses, a straight line distance buffer was used; for analyses of employment and demographic data, census blocks whose borders are within this buffer were used. Figure 1 shows the proposed locations of BRT stations and their service areas based on census blocks. Analyses of the entire BRT service area include data from 771 census blocks. However, due to the dramatic difference in housing, employment, and land use characteristics of downtown Minneapolis compared to other areas served by the Bottineau Boulevard BRT, most analyses in this report were also conducted excluding existing downtown transit stations (Nicollet Avenue, 5th Avenue, Gateway Ramp) and their service areas. These analyses included data from 630 census blocks.

**Land Use Patterns**

As previously mentioned, the land uses surrounding the Bottineau Boulevard Corridor differ greatly from region to region. Figure 2 illustrates the existing land uses in proposed Bottineau Boulevard BRT station service areas. The northernmost section of the corridor is currently characterized largely by low-density retail development and industrial uses. The middle section of the corridor, which runs from the southern border of Brooklyn Park through Crystal, Robbinsdale, and the Near North neighborhood of Minneapolis, on the other hand, is surrounded primarily by single family dwellings and an increasing number of multiple family developments as the corridor enters Minneapolis. The corridor travels through a second highly industrial area as it passes through the Plymouth Avenue and 6th Avenue stations, which are located near the Bassett Creek and Mississippi River industrial centers. Finally, the BRT enters downtown Minneapolis, characterized by large amounts of retail, institutional, mixed use,
and office spaces. This combination of land uses shows that the Bottineau Boulevard BRT will provide a transit connection for the residents of Crystal, Robbinsdale, and Near North Minneapolis to several major employment areas and may offer an alternative mode for some commuters. The areas that will be served by this corridor (excluding downtown Minneapolis) are not currently served by transit or are perceived to be underserved, which is an opportunity; however, the low-density land uses surrounding some stations could be a threat. The number of commuters that could be served by the Bottineau Boulevard BRT depends in large part on the employment patterns of station area residents, which the remainder of this report will address.

**Figure 2.** Land Uses in Bottineau Boulevard BRT Station Service Areas

**Population**

In 2000, census blocks within proposed BRT station service areas had a total population of 39,588 according to the US Census. Approximately 20% of these residents lived in downtown Minneapolis. Figure 3 shows the total population, number of workers, and number of jobs in each non-downtown station’s service area. (Due to overlap in some stations’ service areas these figures add up to more than 100 percent.) Stations located in the Near North neighborhood of Minneapolis had the largest service area population, followed by Robbinsdale, downtown Minneapolis, and Brooklyn Park stations.
Figure 3. Employment and Housing Characteristics of Proposed BRT Station Service Areas

**Workers**

Information about the number of individuals living and working in BRT station service areas can be obtained from the Longitudinal Employment-Housing Dynamics (LEHD) dataset. LEHD is a collaborative program between states and the U.S. Census Bureau that combines state administrative data on employers and employees with census data. LEHD data is updated annually and provides detailed information about employment and commuting patterns that is increasingly being used in transportation planning applications.

According to the most recent LEHD data available from the Census Bureau, 16,751 residents of BRT station service areas were employed in 2003. Approximately 22% of these workers lived in downtown Minneapolis. As Figure 3 shows, the Penn Avenue BRT station had the largest total population and number of employed residents in its individual service area. However, the percentage of the population that was employed in this station’s service area (and in the Near North Minneapolis service area as a whole) was relatively low compared to other areas served by the BRT. Overall, the largest number of workers lived in the service area of Robbinsdale stations, followed by downtown Minneapolis, Near North Minneapolis, and Brooklyn Park.


Jobs

The number of jobs located within BRT stations’ service areas can also be derived from the LEHD. In 2003, two-thirds of the proposed BRT stations had a larger number of jobs than employed residents in their service area. In total, 137,502 jobs were located in census blocks within one third mile of stations; however, the vast majority of these jobs were located in downtown Minneapolis. Excluding downtown Minneapolis, a total of 29,970 jobs were located in the Bottineau Boulevard BRT service area. The largest numbers of jobs were located in the service area of Osseo/Maple Grove stations, followed by Brooklyn Park and Robbinsdale.

Commuting Patterns

Figure 4 shows the commuteshed for BRT station service areas, or the areas where people who live near proposed BRT stations travel to work. The area around each BRT station that is shaded in dark blue/gray indicates the study area for this analysis – year 2000 census blocks within one third a mile of a proposed BRT station. The other colored polygons on the map indicate the number of BRT station area residents that work in each census tract. As the map shows, downtown Minneapolis businesses are by far the largest employers of BRT service area residents. Of the 16,751 workers who lived in BRT station service areas in 2003, 15 percent (2,588) traveled to downtown Minneapolis to work. BRT service will likely attract a portion of these commuters due to the attractiveness of BRT compared to existing bus service and because these workers’ places of employment are within one third mile of BRT stations, a distance that most transit users are willing to walk. The next largest employment location for BRT service area residents is north of I-394 between Highways 100 and 169 (in or near the General Mills complex). In 2003, 557 BRT area residents commuted to this location. Although the express routing of the BRT will run past this area, it will not be serviced by a stop.
Areas with large numbers of commuters from the BRT service area that will not be served by the Bottineau Boulevard BRT line include southeast Plymouth, northeast Eden Prairie, downtown St. Paul, and the University of Minnesota. However, a large number of station area residents also work in areas near proposed BRT stations in Maple Grove, Brooklyn Park, southern Robbinsdale, and the Warehouse District of Minneapolis. These residents are most likely to benefit from BRT service and consider shifting commute modes. Figure 5 shows the number of BRT station area residents who worked within the service area of each BRT station in 2003. Overall, 3,993 workers who lived in the BRT service area commuted to work in an area that will be served by the BRT. As discussed previously and illustrated by Figure 5, the majority of these internal commuters work at jobs near existing downtown transit stations that will be served by the BRT; just over a third (1,405) of internal commuters work at jobs in BRT service areas outside of downtown. The most common destinations for internal commuters who work outside of downtown are: the 6th Avenue station area, which includes Minneapolis’s Warehouse District; the 34th Avenue station area, which includes North Memorial Hospital; and the Brooklyn Boulevard station area, which is surrounded primarily by retail and industrial uses.
Another important aspect to consider when measuring the potential impact of the Bottineau Boulevard BRT is not only where station area residents travel to get to work, but also where employers in the BRT service area draw their workforce from. The area that an employer draws its employees from is referred to as the employer’s laborshed. Figure 6 shows the laborshed for employers in the BRT service area. It is important to note that for this analysis employers near existing transit stops in downtown Minneapolis (Nicollet Avenue, 5th Avenue, Gateway Ramp) were excluded. As a result, this map shows the laborshed only for employers in areas that will receive new or enhanced transit service from the Bottineau Boulevard BRT line. As Figure 6 indicates, a large number of individuals who worked in the non-downtown BRT service area in 2003 commuted from census tracts around the northern end of the Bottineau Boulevard corridor. One quarter (7,627) of the 29,970 jobs in the non-downtown BRT service area were held by workers who commuted from the areas marked in red on this map; over half were held by workers who commuted from the areas across northeastern Hennepin County marked in red and orange.

Data Source: Local Employment and Housing Data 2003

Figure 5. Numbers of BRT Service Area Residents Working Near Proposed BRT Stations
Distance Decay and Transit Demand

This part of the study seeks to produce evidence of people’s actual travel behavior with reference to travel by public transit. Travel behavior is examined for several types of trip purposes to understand individuals’ willingness to walk or drive a given distance to reach a transit station. The tool to be used to understand individual’s willingness to travel is that of distance decay functions. Distance decay is a concept that is familiar to conventional transportation planning practice as an integral part of methods to model the distribution of trips throughout urban space. The key element of distance decay functions is a parameter that describes the spatial reach of trips by a particular mode for a particular purpose (e.g. home-based work trips by auto). This parameter is typically interpreted in terms of travelers’ willingness to travel a given distance, or alternatively as a measure of impedance to travel that characterizes transportation networks and the distribution of activities that they serve. In planning practice, trip purposes are highly aggregated in order to expedite the process of travel forecasting. Little is known, then, about how far people will travel to reach a variety of destinations, and whether there are potentially significant differences between types of destinations.
Data Source

The primary source of data for the estimation of travel behavior in the Twin Cities region is the Metropolitan Council’s 2000 Travel Behavior Inventory (TBI). However, a detailed on-board survey of transit users was also authorized by the Metropolitan Council and conducted in 2005. These data were collected primarily to update the mode choice sub-model of the Council’s forecasting model system and include data on trip origins and final destinations, as well as points of access and egress from transit stops and stations. The inclusion of this data set allowed for a more highly disaggregated analysis of transit use, including stratification by trip purpose, access mode and type of service.

The on-board survey was conducted with a stated goal of completing 22,000 valid surveys for the transit system. Targets were set to collect minimum samples based on service type (local, express, and commuter bus, light rail) and peak/off-peak strata. The on-board survey data were more limited in terms of their treatment of trip purpose, since the objective of the survey was simply to identify characteristics relevant to travel forecasting models. Trip purposes identified in the survey were limited to general purposes of work, school (K-12), college/university, shopping and ‘other’.

Transit distance decay

Analysis of travel behavior by users of public transit modes is more difficult, since trips are comprised of separate collection, line-haul and distribution segments, often made by different modes. In addition, different types of transit service (local and express bus, light rail) have different operating characteristics, the most important being speed. Ideally, one would like to account for all of these sources of variability in describing the travel behavior of transit users, but data limitations preclude this level of detail. Instead, we begin with aggregate descriptions of distance decay functions for transit users, then seek to disaggregate to the greatest degree possible by trip purpose, access mode (walk and auto), and service type. Furthermore, we focus our attention on home-based trips that do not require transfers in order to limit the uncertainty in travel distance calculations where multiple routes exist between origins and destinations.

Trip Purpose

As with the pedestrian and bicycle modes, the disaggregation of trips by purpose is of primary interest in this study. The on-board rider survey data used to estimate decay functions for transit trips contained a more limited range of trip purposes that the Travel Behavior Inventory. Trip purpose analyses were therefore mostly limited to trips for work, shopping and college or university educational purposes. A summary of the distance decay curves for transit trips made for these purposes is provided in Figure 6.
As one would expect, work trips tend to be longer-distance trips, covering distances of 50 or more KM with some regularity. Trips for shopping or college purposes were shorter and broadly similar in terms of responding to the effects of distance. Using aggregate trip purpose data does obscure some of the underlying differences in the characteristics of travel for each purpose, though. On one hand, many of the transit users making trips identified as being for college or university purposes may include students, many of whom live relatively short distances from campus and make short daily commute trips by bus. These are counterbalanced by students (and some faculty or staff) commuting longer distances and using the network limited-stop and express bus routes directly serving the university. These types of trips would show up as the less frequent observations in the long tail of the decay curve. A related issue is the effect of access mode and service type on trip length. Many transit work trips are longer than other types of transit trips because travelers are using higher-speed services such as express bus and light rail, allowing greater distance to be covered without much additional travel time. In addition, more of the users of these types of services are likely to use auto as an access mode, increasing overall trip speeds.

This latter effect can be examined by disaggregating the trips by both access mode and trip purpose. Given the hypothesis that travelers have a more or less fixed budget of travel time, transit users who access transit by walking to a station or stop would be expected to make shorter trips, since they are in principle trading off access (and perhaps also egress) time against time spent on the line-haul portion of the trip (i.e. time spent in-vehicle), thus generating shorter overall distances. One can also confirm these differences visually by examining the curves for trips by walk and auto access presented in

Figure 6: Distance Decay Curves for Transit Trips by Purpose

Figure 6 shows the distance decay curves for transit trips by purpose. The curves are differentiated by purpose: work, college, and shopping. The x-axis represents distance in kilometers, while the y-axis represents the percent of trips. The curves indicate that work trips tend to be longer-distance trips, covering distances of 50 or more KM with some regularity. Trips for shopping or college purposes were shorter and broadly similar in terms of responding to the effects of distance. Using aggregate trip purpose data does obscure some of the underlying differences in the characteristics of travel for each purpose, though. On one hand, many of the transit users making trips identified as being for college or university purposes may include students, many of whom live relatively short distances from campus and make short daily commute trips by bus. These are counterbalanced by students (and some faculty or staff) commuting longer distances and using the network limited-stop and express bus routes directly serving the university. These types of trips would show up as the less frequent observations in the long tail of the decay curve. A related issue is the effect of access mode and service type on trip length. Many transit work trips are longer than other types of transit trips because travelers are using higher-speed services such as express bus and light rail, allowing greater distance to be covered without much additional travel time. In addition, more of the users of these types of services are likely to use auto as an access mode, increasing overall trip speeds.
Figures 7 and 8. Trips with walk access for shopping and college purposes are generally confined to distances of less than 20 KM, while work trips are as longer as 35 KM. By contrast, trips with auto access tend to be longer, with overall distances of up to 50 KM for college trips and nearly 60 KM for work trips.

Transit trips with auto access trips also appear to have a distance threshold (in the range of 5-10 KM) below which users will not use this combination of access and line-haul modes. This finding also indicates that a negative exponential curve is not appropriate for capturing the distance decay effect for this type of trip. Figure 8 plots the exponential curves in addition to points that trace out the shape of the curves using predictions from a more general decay function.

Note that trips for shopping purposes with auto access are not available in the analysis. Small sample sizes precluded this effort. Within the reduced set of transit data used for the analysis of transit trips (excluding trips that required transfers, non-home based trips and trips where origins and destinations could not be identified and geocoded), shopping trips were a limited subset. Moreover, most of these trips involved walking as an access mode.
Another useful way to disaggregate transit trips in order to isolate the effects of speed on distance is to stratify trips by service type. The detailed data available from the on-board survey of transit users permits this type of analysis. Users are stratified according to three major service types: express bus, light rail and local bus. The curves fit for transit trips by service type are shown in Figure 9. Again, there appear to be threshold effects for each of the service types, though they are more pronounced for express and light rail trips. Trips by local bus appear to be considerably shorter than express bus and light rail. This can be partly accounted for by the different operating speeds of the services, but also by the tendency of express bus services (and to a smaller extent, light rail services) to be used extensively for work trips, which tend to be longer than average regardless of mode.

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2 A fourth type, commuter bus is also included in the survey. This service is characterized by long-distance trips and a premium quality of service. However, at the time of the survey only one such route existed, indicating little value to treating this as a separate class of service for analytical purposes.
Figure 9: Distance Decay Curves for Transit Trips by Service Type