Public Transportation

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Ridership and Revenue Implications of Free Fares
for Seniors in Northeastern Illinois
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Eliminating Bus Stops: Evaluating Changes in Operations, Emissions and Coverage

Ranjay M. Shrestha and Edmund J. Zolnik
George Mason University

Abstract

Bus systems in the United States are unattractive to many potential riders because of their lack of efficiency, especially with regard to travel time. One of the reasons services are not more efficient has to do with the spacing of bus stops. After using a nearest facility algorithm with an 800 m walking distance threshold to identify eligible bus stops in the current bus system in the city of Fairfax, Virginia, the impacts of their elimination on operations, emissions, and coverage are estimated. Results indicate that eliminating some bus stops (about 40% of current stops) could improve travel times and reduce operating costs by the same percentage (23%). In addition, bus-related emissions such as CO (34%), VOC (18%), and NOx (10%) could all be substantially lower. Surprisingly, the loss in coverage due to eliminating stops would not be large (10% of the total population of the city of Fairfax).

Introduction

One of the reasons bus service in the United States is unpopular is because it is inefficient; it takes too long to get riders to their destinations. Many attribute this inefficiency to the spacing of bus stops (Furth et al. 2007). Densely-spaced bus stops improve geographic coverage and rider accessibility, but they also increase in-vehicle time and supply costs (Chien and Qin 2004). Sparsely-spaced bus stops,
on the other hand, yield faster services and lower operating costs even if ridership accessibility is lower (Murray and Wu 2003).

This study focused on bus service in the city of Fairfax, Virginia, also known as the City-University-Energysaver (CUE) bus system, which serves George Mason University (GMU). Currently, the CUE bus provides service to local residents and GMU students in the city of Fairfax who need access to campus as well as other modes of transportation such as light rail. The primary objective was to estimate the operating costs savings and emission reductions that could be realized by eliminating some stops on CUE bus routes. The secondary objective was to determine if it is possible to eliminate some CUE bus stops without adversely affecting service coverage. To meet the latter objective, equity and tradeoff analyses were performed by looking at the characteristics of stops and the people who would lose coverage if some of the stops on the current CUE bus routes were eliminated.

The second section provides background on bus stop spacing and the costs and benefits (economic, environmental, and social) of eliminating some of them. The third section discusses the data used in the study and the study area. The fourth section discusses the methods used to identify bus stops eligible for elimination and explores the service improvements which could result from their elimination. The fifth section presents the results of the study and the effect that eliminating some stops could have on the populations currently served by the CUE bus. The last section presents the conclusions of the study and avenues for future research.

**Background**

**Public Transportation Today**

The quality of bus service is perceived differently by different users. From the user’s perspective, bus service quality is usually based on availability, frequency, travel speed, reliability and safety (Pratt 2000; Rood 1999; Phillips et al. 2001; Kittelson & Associates 2003; Kihl et al. 2005; Marsden and Bonsall 2006; Litman 2007; 2008; Stradling et al. 2007; Kenworthy 2008). Although these are equally important for bus service evaluation, due to data availability and time constraints, this study evaluated the service quality improvements that could be realized by eliminating some stops on CUE bus routes in terms of travel time. In addition, it explored how operating costs, transit-based emissions, and population coverage would change if some CUE bus stops were eliminated.
Stop Spacing

One way of improving the efficiency of bus service is via the appropriate spacing of stops. The proper spacing of stops can significantly improve the quality of bus service by decreasing travel times (Wirasinghe and Ghoneim 1981; Kocur and Hendrickson 1982; Fitzpatrick et al. 1997; Kuah and Perl 2001; Saka 2001; Chien and Qin 2004; Alterkawi 2006; Ziari et al. 2007). One of the key issues for determining the appropriate locations of bus stops is to have an understanding of how far people are willing to walk to get to the facilities (Ziari et al. 2007). Determining walking distance to and from bus stops presents two issues: knowledge of rider origins and destinations, and feasible walking distances along street networks (Furth et al. 2007).

One common method of identifying origins and destinations within bus service areas is to use the centroid of the population in those areas (Murray 2001; Saka 2001; Murray 2003; Furth et al. 2007). Because it is difficult to find the center of a population, the center points of individual blocks are often used to approximate population centers (Bielefeld et al. 1995; McElroy et al. 2003). Generating parcel-based centroid points using the parcel-network method would provide a highly detailed level of spatial accuracy regarding population coverage (Biba et al. 2010). However, due to a lack of parcel-level data, this study used block-level data to create service areas. Furthermore, unlike past research that used Euclidean distance to measure walking distances between origins and destinations (Okabe et al. 2008; Gutierrez and Gracia-Palomares 2008), the study used actual road network distances.

Another key issue is the appropriate walking distance to the facility. Accessibility to public transit is typically characterized as a reasonable walk under normal conditions (Murray 2003). Usually, facilities are located based on the simplified demand in the service areas (Wirasinghe and Ghoneim 1981; Brouwer 1983; Fitzpatrick et al. 1997). Others assume that it depends on population density—lower density corresponds to longer walking distances (Saka 2001; Ziari et al. 2007). Typical walking distances range from 400 m to 800 m. In this study, different walking distances between 400 m and 800 m were used to see how they impact bus service coverage.

Calculating bus travel times is also important for measuring improvements in bus service. Two basic delay factors—dwell time and acceleration/deceleration time—make buses slower; that is, they increase total bus travel times (Saka 2001; Chien and Qin 2004; Ziari et al. 2007). Although Global Positioning Systems (GPS) and Geographic Information Systems (GIS) are frequently used to estimate these delays
(Srinivasan and Jovanis 1996; Hellinga and Fu 1999), the study used different delay variables to calculate them.

Costs and Benefits
Besides understanding the primary benefit of more efficient travel times that could be achieved by eliminating bus stops, it is also important to understand what other costs and benefits could be associated with this course of action (Savage 2009). This is known as impact analysis and entails an analysis of the impacts of changing transit services (Litman 2004). Research on public transit system improvements tends to adopt different perspectives. Most focus on the economic, environmental, and spatial effects of improving public transit service (Polzin 1999; Kennedy 2002; Bento et al. 2005; Brownstone and Small 2005; Harford 2006). Therefore, this study focused on the following tradeoffs of improved service on the CUE bus: economic effects (operating cost reductions), environmental effects (emission reductions), and spatial effects (residential service coverage). By analyzing the tradeoffs of reduced travel times that could be achieved by eliminating stops on the CUE bus routes, the study estimated the different impacts that could result from the change in transit service.

Economic Effects: Operating Cost Reductions
There are various ways to perform an economic analysis of a bus system. However, to estimate the financial impacts of two different routes, the differences in their operating costs provide a direct monetary comparison (Karlaftis and McCarthy 1999). Benjamin and Obeng (1990) found that reductions in operating costs for public transit could be achieved by increasing vehicle efficiency. In the United States, all operating costs that are not covered by bus fares come from either taxation through dedicated revenues or local, state, and federal government tax-derived monies (Harford 2006). It was, therefore, important to understand the financial savings that could be achieved by eliminating some stops on the CUE bus system.

Environmental Effects: GHG Emissions Reductions
Transportation is one of the major contributors to air pollution in the United States. Among the different sources of air pollution, on-road vehicle emissions are responsible for about 45 percent of the Environmental Protections Agency’s (EPA’s) 6 criteria pollutants (National Research Council 1995). Of the different greenhouse gases (GHGs) emitted by vehicles, carbon monoxide (CO), volatile organic compounds (VOCs), and nitrogen oxide (NOx) contribute the most (Grant et al.
CO and VOCs are emitted from the incomplete combustion of fossil fuels, whereas NO\textsubscript{x} is the product of high-temperature chemical processes that occur during the combustion process in the engine itself (National Research Council 1991). Even though emissions from diesel-fueled vehicles such as buses are only five percent of on-road vehicle emissions, emission rates for such heavy-duty vehicles are higher since they operate at higher combustion pressures and temperatures than gasoline-fueled vehicles (Lilly 1984). This means that even though their relative contribution to on-road vehicle emissions is limited, heavy-duty vehicles such as buses are highly hazardous to the environment. This study, therefore, explored the environmental benefits that could be realized by eliminating stops on CUE bus routes in terms of GHG emission reductions.

There are many ways to measure the amount of GHGs emitted by different types of vehicles. In fact, vehicle emissions are a function of several variables grouped into four main categories: travel-related factors, driver behavior, highway network characteristics, and vehicle characteristics (National Research Council 1995). In this study, only travel-related factors varied between the old (all current stops) and the new (without some stops) CUE bus routes, whereas the rest of the variables (driver behavior, highway network characteristics, and vehicle characteristics) remained the same. Travel-related factors included trip/vehicle use and speed/acceleration, which were used to calculate and compare the emissions between the two routes (National Research Council 1995). Trip/vehicle use emissions are simply a function of the total number of trips and total distance traveled by the vehicle. Speed/acceleration emissions are a function of the speed and acceleration of the vehicle over the distance of the trip. Eliminating some bus stops will yield improvements only in the travel speeds of buses. This means that other travel-related factors such as vehicle miles traveled and numbers of trips will not be affected by eliminating some bus stops. This study, therefore, used only the speed/acceleration factor to calculate and compare the emissions differences between the old and the new CUE bus routes.

**Spatial Effects: Residential Service Coverage**

Eliminating some stops on the CUE bus routes could have an effect on residential service coverage. It was, therefore, important to explore the characteristics of riders who use the CUE bus to evaluate the costs of eliminating some of the bus stops that serve them. Exploring the demographic profiles of riders also helps to characterize the people who use public transit (Neff and Pham 2007) and derive
a relationship between public transit and the people that could be affected by changes in service (Polzin 1999).

**Data**

**GMU Commuting Survey**

GMU conducted a survey of faculty/staff and students in 2007 to better understand their commuting behavior. They were particularly interested in the factors that most influenced mode choices to campus for those living in the city of Fairfax. Results suggest that among 1,000 respondents, more than 75 percent of those who lived up to six miles from campus reported that commuting time was one of the main reasons for driving to campus. They further felt that current CUE bus service was not efficient enough, especially with respect to travel times.

**Data Sources**

Demographic data for the block groups in the study area are from the United States Bureau of the Census. Block group boundaries and road network data are from Environmental Systems Research Institute (ESRI). Two CUE bus routes (Gold and Green) along with their corresponding bus stops were created from the road network data from ESRI. Current CUE bus travel times and schedules were obtained from the City of Fairfax. Financial information on the CUE bus service for the year 2008 are from the National Transit Database (2008). The data include different operational and non-operational expenditures associated with the CUE bus service. Information on the fuel types used on the CUE buses was from the City of Fairfax. For the GHG emissions estimates, factors based on the speed of the CUE buses are from the Metropolitan Washington Council of Governments (MWCOG) (2010).

**Study Area**

The study area included the block groups served by the CUE bus routes within the city of Fairfax. In addition, several block groups from within the jurisdiction of Fairfax County were included because they are also served by CUE bus routes. Two of these block groups from within Fairfax County include GMU and the Vienna/Fairfax-GMU Metro station, which is the last westbound stop on the Orange Line. Figure 1 is a map of the study area including the CUE bus routes.
Figure 1. CUE bus routes with stops and block-level population


**Methods**

*Equity Analysis*

It appeared that analyzing the tradeoffs of eliminating some stops on the CUE bus routes may be amenable to standard cost-benefit analysis (Litman 2009). However, further reflection revealed that some of the costs of eliminating some stops was not easily monetized. For example, costs attributable to shrunken residential service coverage are usually classified as social costs. Monetizing such social costs is difficult. Therefore, standard cost-benefit analysis may not provide an accurate estimate of the tradeoffs related to residential service coverage.

One way to account for such social costs is via equity analysis (Litman and Doherty 2009). In simple terms, equity refers to the distribution of various social and/or economic impacts and whether those distributions are considered appropriate (Litman 2002). Equity analysis generally is considered a complicated procedure, as there is no single way to evaluate equity. Evaluation usually depends on the type of equity, the way people are categorized, which impacts are considered, and how equity is measured.

In the study, transportation equity was measured by the reduction in operating costs, the reduction in GHG emissions and the improvement in overall fleet speed that could result from eliminating some stops on the CUE bus routes. Access to bus service was measured by estimating the extent of the changes in residential service coverage that could result from eliminating some stops on the CUE bus routes. Additionally, the demographic profiles of the residents who would no longer be serviced by the CUE bus routes after their stops had been eliminated was also taken into consideration in the equity analysis. This helped to assess the potential social costs of eliminating some of the stops on the CUE bus routes.

*Walking Distance Thresholds*

Using block group centroids to represent service areas and bus stops to represent facilities, a network analysis was undertaken to find the nearest facilities within different walking distances from the centroids. The network analysis used a shortest path algorithm to find the closest facility for each service area. In less densely-populated areas, such as the city of Fairfax, the most realistic walking distance threshold is 800 m (Demetsky and Lin 1982; Saka 2001; Ziari et al. 2007). It is also the most conservative walking distance threshold, given that most riders in North America (75–80%) walk 400 m or less to bus stops (Kittelson & Associates 2003). However, to better understand how different walking distances change residential
service coverage, walking distances of 200 m, 400 m and 600 m were also tested. In addition, the network analysis was undertaken without any walking distance threshold to ensure that all of the service areas were covered. This latter analysis offered a glimpse of the maximum number of facilities required to provide complete coverage in the study area.

**Eliminating Bus Stops**

After undertaking the nearest facility analysis for all five walking distance thresholds (200 m, 400 m, 600 m, 800 m and none), the minimum number of bus stops used at each walking distance was obtained. Those facilities that were not selected at any of the walking distance thresholds were assumed to be eligible for elimination. The reasons that some bus stops were never selected, no matter the walking distance threshold, was because some of the census block centroids were beyond the maximum walking distance threshold (800 m) or the closest census block centroid was already served by another bus stop. In either case, those bus stops that were never selected were labeled as eligible for elimination. Figure 2 is a map of the study area including the CUE bus routes and the stops that were eliminated.

![Figure 2. CUE bus routes, stops, and eliminated bus stops](image)
Based on previous research (Demetsky and Lin 1982; Saka 2001; Murray 2003; Ziari et al. 2007) and given that many of the block groups in the study area are sparsely populated, 800 m was an appropriate walking distance benchmark for the study. Using the 800 m walking distance threshold, therefore, those bus stops that were not selected were eliminated from the CUE bus routes.

**Bus Stop Delays**

Two factors that contribute significantly to time delays at bus stops are acceleration/deceleration delay and dwell time delay. These delays can consume up to 26 percent of total bus travel times (Rajbhandari et al. 2003). Acceleration/deceleration delay occurs when the bus is pulling in or out of the bus stop. Dwell time delay refers to the time delay to load and unload riders at bus stops. The two factors are calculated from the following equations (Saka 2001; Chien and Qin 2004; Ziari et al. 2007). The first equation calculates the time delay due to decelerating/accelerating:

\[
T_{\text{acc/dec}} = \left( \frac{V}{\text{acc}} \right) + \left( \frac{V}{\text{dec}} \right),
\]

where

\[T_{\text{acc/dec}} = \text{acceleration/deceleration delay}\]
\[V = \text{bus cruising speed (m/s)}\]
\[\text{acc} = \text{bus acceleration (m/s}^2\)]
\[\text{dec} = \text{bus deceleration (m/s}^2\)]

By multiplying the total number of riders by the dwell delay for each rider, the following equation calculates the total dwell time delay for each bus stop:

\[
T_w = Q \times w,
\]

where

\[T_w = \text{dwell time delay (s)}\]
\[Q = \text{number of riders at the stop}\]
\[w = \text{time to board/unboard each rider}\]

Cruise speed \(V\) and acceleration/deceleration \(\text{acc/dec}\) were from the current CUE bus schedule. The cruise speed was about 12 m/s (~27 mi/hr), and acceleration and deceleration was about 2 m/s² (Furth and SanClemente 2006). Data for
other time delay variables were from direct observation on the CUE bus: the average number of riders at the stops \( Q \) was 4; and the time to board/unboard each riders \( w \) was 5 s. Using the above equations and data, the time delay at each stop on the CUE bus route \( T_w \) was 20 s. It is important to note that this time delay was based on an observed number of riders per stop who on-boarded and off-boarded the CUE bus. Because it was an average for all stops, it masked differences between stops in the number of riders who on- and off-boarded the bus, the speed with which subsequent riders were able to board the bus after the initial rider boards the bus and the effects of near- and far-side stops on time delays. Each of these issues was important in the calculation and sensitivity of the time delay estimates and is, therefore, worthy of future research.

**Total Travel Time**

The following equation calculates total travel time for the new bus routes (Saka 2001):

\[
T_{bus} = N \times \left( T_{acc/dec} + T_w \right) + T_v ,
\]  

where

\( T_{bus} \) = total bus travel time

\( N \) = total number of bus stops

\( T_v \) = time for CUE bus to make a one-way trip at cruise speed (s)

Total travel time is the time it took the CUE bus to make a one-way trip on the new and old routes. The first part of the equation calculated the total delay at each stop; multiplying that expression by the total number of stops \( N \) resulted in the total delay for a one-way trip. The total delay depends on the number of stops on the route. Using the network analyst tool in GIS, the total route distance estimate was 42,890 m (26.65 mi). Therefore, the time for the CUE bus to make a one-way trip at cruise speed \( T_v \) was 3,574.16 s. Using Eq. (3), the total travel time for both the old and the new CUE bus routes was calculated. The number of bus stops on the old CUE bus route was 121, and the number of bus stops on the new CUE bus route was 68. One assumption of Eq. (3) is that the CUE bus does not skip any of the available stops on either the new or the old routes—an assumption that is not realistic. This means that the total travel time estimates from Eq. (3) for the new and old routes would be higher than the observed total travel times, given that the CUE bus was already making one-way trips faster than expected.
Operating Cost Reductions

Annual operating cost data for the CUE bus are from the National Transit Database (2008). The database includes operating costs for the CUE bus from 2001 to 2008. However, only operating costs for the year 2008 appear in the study to reflect the most recent expenditures. Annual operating costs are in four different categories: operations, maintenance, non-vehicle, and general administrative. Operations costs include operator’s wages, fringe benefits and services. Maintenance costs include fuel and lube, tires, and other. Non-vehicle costs include casualty and liabilities and utilities. Administrative costs include other wages and salaries. Vehicle fleet size is the total number of vehicles available for operations in a given year. Vehicle revenue hour is the hours that vehicles are scheduled for or actually are in revenue service (including layovers and recovery times).

A simple mathematical approach to estimate the total operating costs is to sum all of the costs and then divide by the Vehicle Revenue Hour (VRH), which was $34,602, to get the total cost per hour to operate the CUE bus (Bruun 2005). Following this approach, total operating costs (TOC) and total operating costs per hour (TOCH) were $2,980,627 and $86.14, respectively. TOCH provides a calculation of total operating costs for any given hour of operating the CUE bus. However, it may not accurately reflect total operating costs for the purposes of the study. One of the objectives of the study was to estimate the cost savings in operating the CUE bus that could be realized by eliminating some stops on the route. To that end, some of the subcategories of costs, such as administrative salaries, operations fringe benefits and non-vehicle casualties and liabilities would not be affected by the elimination of some CUE bus stops. The exclusion of the above costs from the calculation of the TOC and TOCH, therefore, provided a more accurate calculation of the costs of operating the CUE bus for the study. The more accurate TOC and TOCH were $1,791,127 and $51.76, respectively.

Emissions Reductions

To calculate CUE bus emissions at cruise speed, emissions factors for diesel buses from the Metropolitan Washington Council of Governments (2010) and the United States Environmental Protection Agency (2003) were used. MWCOG’s approach is based on the EPA’s Mobile6 emissions factors model, which estimates emissions factors based on the average speed of diesel buses. It calculates CO, VOCs, and NOx—including both NO and NO2—depending on average vehicle speed. Even though emissions factors were available from 1990 to 2005, only data for the most recent year were used to make it timelier.
The emissions analysis in the study would be more accurate if carbon dioxide (CO₂) emissions were included. However, because sufficient information on the speed of the vehicle was not available, only CO, VOC, and NOₓ emissions were calculated in the study. Besides, CO, VOC, and NOₓ are the predominant air pollutants from road transportation sources (Grant et al. 2007). On average, in the United States, road transportation sources are responsible for 55 percent of CO, 27 percent of VOC, and 35 percent of NOₓ towards overall GHG emissions.

As mentioned above, the total, one-way route distance for the CUE bus was 42,890 m (26.65 mi) and the total, one-way travel time for the CUE bus was 7,440 s (2.07 hr). Therefore, the cruise speed of the bus was ~13 mi/hr. With this information and the emissions factors from MWCOG, the following equation calculated CO, VOC, and NOₓ emissions from the CUE bus at different cruise speeds:

\[
E = EF \times D,
\]

where

\[
E = \text{CO, VOC, or NO}_{\text{x}} \text{ emissions (g)}
\]

\[
EF = \text{CO, VOC, or NO}_{\text{x}} \text{ emissions factors at different speeds (g/mi)}
\]

\[
D = \text{total CUE bus route distance (mi)}
\]

The results section shows the calculations for emissions reductions that could be realized after eliminating some of the stops on the CUE bus route.

**Results**

**Travel Time Reduction**

Table 1 shows how facility usage and service area coverage would change at different walking distance thresholds. Clearly, eliminating some CUE bus stops has the potential to reduce travel times without unduly affecting service area coverage. At the ideal walking distance threshold (800 m), 56.2 percent of the available facilities were used, but fully 82.5 percent of the service area was covered. This translates to a potential travel time reduction of 23 percent (approximately 28 min) (Table 2). It is important to qualify this estimate because it assumes, as mentioned above, that the CUE bus stops at all available stops. This is not likely, especially during the summer when demand is lower than during the fall and spring semesters. This means that the potential travel time reduction would probably be less than 28 min because the CUE buses would already be skipping some stops.
Table 1. Facility Usage and Service Area Coverage at Different Walking Distance Thresholds

<table>
<thead>
<tr>
<th>Walking Distance Threshold (m)</th>
<th>Total Facilities</th>
<th>Facilities Used</th>
<th>Facilities Used (%)</th>
<th>Total Area (acs)</th>
<th>Service Area (acs)</th>
<th>Service Area (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>200</td>
<td>121</td>
<td>29</td>
<td>24.0</td>
<td>251</td>
<td>51</td>
<td>20.3</td>
</tr>
<tr>
<td>400</td>
<td>121</td>
<td>52</td>
<td>43.0</td>
<td>251</td>
<td>112</td>
<td>44.6</td>
</tr>
<tr>
<td>600</td>
<td>121</td>
<td>66</td>
<td>54.5</td>
<td>251</td>
<td>177</td>
<td>70.5</td>
</tr>
<tr>
<td>800</td>
<td>121</td>
<td>68</td>
<td>56.2</td>
<td>251</td>
<td>207</td>
<td>82.5</td>
</tr>
<tr>
<td>None</td>
<td>121</td>
<td>71</td>
<td>58.7</td>
<td>251</td>
<td>249</td>
<td>99.2</td>
</tr>
</tbody>
</table>

Table 2. Travel Time Reduction between Old and New CUE Bus Routes

<table>
<thead>
<tr>
<th>CUE Bus Route</th>
<th>Stops (n)</th>
<th>Total Delay (s)</th>
<th>Total Travel Time (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Old</td>
<td>121</td>
<td>3,872</td>
<td>7,446</td>
</tr>
<tr>
<td>New</td>
<td>68</td>
<td>2,176</td>
<td>5,750</td>
</tr>
<tr>
<td>Reduction (%)</td>
<td></td>
<td></td>
<td>23</td>
</tr>
</tbody>
</table>

**Operating Cost Reduction**

The impressive travel time reduction means that operating costs could also be reduced by eliminating some of the CUE bus stops. The total operating cost per hour (TOCH) for the CUE bus was $51.76. Multiplying TOCH by the old and new total travel times (2.07 hrs and 1.60 hrs, respectively), the old and new operating costs were $108.70 and $82.82, respectively. Overall operating costs for single, one-way trips by CUE buses could therefore be reduced by $25.88 if some of the stops were eliminated. Because CUE buses made 312 trips per week, the total weekly projected operating cost reduction would be $8,074.56.

**Emissions Reductions**

Using Eq. (4) and the emissions factors for diesel buses, the GHG emissions reductions that could be realized by eliminating some CUE bus stops are as follows. For the old route with a cruise speed of 13 mi/hr, emissions of CO, VOC, and NO\textsubscript{x} are 1.23 lb, 0.11 lb, and 1.21 lb, respectively. For the new route with a cruise speed of 17 mi/hr, emissions of CO, VOC, and NO\textsubscript{x} are 0.82 lb, 0.09 lb and 1.09 lb, respectively. GHG emissions could, therefore, be reduced by eliminating some of the stops on the CUE bus—CO could be reduced by 33.34 percent, VOC could be reduced by 18.18 percent, and NO\textsubscript{x} could be reduced by 9.92 percent. Interestingly, Table 3 and Figure 3 show that annual emissions of the GHG emissions CO and NO\textsubscript{x} would
decrease the most over the range of eliminated stops on the CUE bus (0 to 53 stops eliminated).

**Table 3. Number of Stops Eliminated and Changes in Population, Costs, Travel Times, and Emissions**

<table>
<thead>
<tr>
<th>Stops Eliminated (n)</th>
<th>Population Coverage (%)</th>
<th>Annual Cost Reduction ($)</th>
<th>Travel Time Reduction (min)</th>
<th>Emissions (lb/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>CO</td>
</tr>
<tr>
<td>53</td>
<td>89</td>
<td>407,517.59</td>
<td>29</td>
<td>12,292.60</td>
</tr>
<tr>
<td>50</td>
<td>99</td>
<td>384,450.56</td>
<td>27</td>
<td>13,610.76</td>
</tr>
<tr>
<td>30</td>
<td>99</td>
<td>230,670.34</td>
<td>16</td>
<td>16,896.57</td>
</tr>
<tr>
<td>20</td>
<td>99</td>
<td>153,780.22</td>
<td>11</td>
<td>17,508.31</td>
</tr>
<tr>
<td>10</td>
<td>99</td>
<td>76,890.11</td>
<td>5</td>
<td>18,065.10</td>
</tr>
<tr>
<td>5</td>
<td>99</td>
<td>38,445.06</td>
<td>3</td>
<td>18,325.16</td>
</tr>
<tr>
<td>0</td>
<td>99</td>
<td>0.00</td>
<td>0</td>
<td>18,472.43</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>VOC</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1,360.97</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1,402.32</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1,506.39</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1,543.10</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1,576.50</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1,592.11</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1,600.94</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>NOx</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>16,252.57</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>16,549.06</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>17,280.78</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>17,589.71</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>17,870.89</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>18,002.22</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>18,076.59</td>
</tr>
</tbody>
</table>

**Figure 3. Changes in annual emissions by number of stops eliminated**
Tradeoffs

Eliminated Bus Stops by Category

All of the CUE bus stops, both eliminated and retained, were categorized as either commercial, recreational, residential or shopping stops. The categorization of bus stops was based on inspection of the CUE bus route map and observations from riding the CUE bus. Stops close to major commercial landmarks such as restaurants, banks, metro stations and schools were categorized as commercial stops. Stops close to housing units were categorized as residential stops and stops close to park and recreational facilities are categorized as recreational stops. Finally, stops close to shopping centers were categorized as shopping stops. Table 4 shows the tally of these bus stops. Among the 53 bus stops that were eliminated from the old route, 15 were commercial, 21 were recreational, 3 were residential, and 14 were shopping stops. Similarly, among the 68 bus stops that were retained from the old route, 35 were commercial, 10 were recreational, 3 were residential, and 20 were shopping stops.

Table 4. Categorization of Eliminated and Retained Stops

<table>
<thead>
<tr>
<th>Category</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Eliminated</td>
<td>Retained</td>
</tr>
<tr>
<td>Commercial</td>
<td>14</td>
<td>20</td>
</tr>
<tr>
<td>Recreational</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Residential</td>
<td>15</td>
<td>35</td>
</tr>
<tr>
<td>Shopping</td>
<td>21</td>
<td>10</td>
</tr>
<tr>
<td>Total</td>
<td>53</td>
<td>68</td>
</tr>
</tbody>
</table>

Looking further into the categories of bus stops that were eliminated, 68 percent \((21 \div 31) \times 100\%\) of the shopping stops were eliminated. Furthermore, 41 percent \((14 \div 34) \times 100\%\) and 30 percent \((15 \div 5) \times 100\%\) of the commercial and residential stops, respectively, were eliminated. Fifty percent \((3 \div 6) \times 100\%\) of the recreational stops were eliminated, but because recreational stops make up such a small percentage of all CUE bus stops \((6 \div 121) \times 100\% = 5\%\), the loss of recreational stops was actually small. The loss of shopping stops means that residents would have to walk further to either the next nearest bus stop or to the shopping center itself. However, because most people do not use public transit for shopping trips, particularly food shopping trips, the elimination of these stops would not be as significant as it first appears.
Residential Service Coverage

One difficulty of capturing the residential population that lives within proximity of the eliminated bus stops was choosing the appropriate buffer distance between the bus stop and the population center. Murray (2003) suggested that 400 m would be an ideal buffer distance for a city area to estimate the effect of eliminating bus stops. Others have suggested suitable buffer distances from 200 m to 300 m (Ziari et al. 2007). In this study, a middling buffer distance of 300 m was used to capture the population that would be most affected by the elimination of some CUE bus stops.

The coverage analysis using a 300 m buffer distance around the 15 residential bus stops that were eliminated shows that 3,588 residents (approximately 10% of the city of Fairfax's population) would be affected. The demographic analysis on the residential population was further broken down into various racial groups living within proximity of the eliminated bus stops. White residents (57%) would be most affected, followed by Hispanic (20%), Asian (15%), and African American (5%) residents. Other residents, including Native Americans and Asian and Pacific Islanders, made up the remaining 3 percent of the affected resident population. Further demographic analysis shows that none of these racial groups would be disproportionally affected by eliminating those 15 bus stops.

Residents living within proximity of the eliminated bus stops who are members of other groups may also be adversely affected. In particular, residents who are 65 years of age or older and no longer participating in the labor force may prefer more accessible stops over faster bus service. For these residents, time is not as important as access. Demographic analysis on the resident population, however, showed that few residents in the study area were 65 years or older. This is consistent with the housing pattern at the Fairfax campus of George Mason University, where off-campus accommodations for undergraduate and graduate students makes up for a lack of on-campus accommodations. This also makes the results of the study less generalizable to different geographies with a more balanced demographic profile of younger and older residents.

Conclusions

According to our model, eliminating some of the stops on the current CUE bus route could reduce one-way travel times and operating costs by a projected 23 percent. The observed magnitude of the travel time reductions needs to be verified with data on speed differences based on bus stop densities; however, improving
travel times would boost ridership. In addition, savings from lower operating costs could be used to improve other aspects of the CUE bus service (for example, reducing fares or improving bus stop facilities) to further boost ridership. In addition to the operations benefits, eliminating some bus stops would be good for the environment. The new route could reduce GHG emissions of CO, VOC, and NO\textsubscript{x} by 34, 18 and 10 percent, respectively. On average, the new route could reduce annual GHG emissions of CO, VOC, and NO\textsubscript{x} by 6,278, 241, and 1,789 lbs, respectively. For year 2008, the total amount of on-road vehicle emissions nationwide of CO, VOC and NO\textsubscript{x} was approximately 38, 2.5 and 4.2 mil tons (United States Environmental Protection Agency 2009). While the potential GHG emissions reductions that could result from eliminating some stops on the CUE bus route may pale in comparison to nationwide GHG emissions, these reductions would be significant for the city of Fairfax. Finally, only 10 percent of the resident population of Fairfax would be directly affected by eliminating some of the CUE bus stops. This latter finding suggests that resident service coverage would likely not be a problem.

Transit riders are sensitive to comfort and convenience improvements in service (Phillips et al. 2001; Litman 2004; Litman 2008). And, surely, they are sensitive to the elimination of service. One limitation of the study, therefore, is that the tradeoff of lost ridership due to the elimination of more accessible bus stops was not taken into consideration. For example, the policy of the CUE bus is not to stop between stops to load or unload riders. This policy could raise objections from riders who are fearful of walking longer distances to the next nearest bus stop, especially in the dark (though adoption of a more flexible policy to stop at night between stops could address such objections). Another limitation is that the study did not attempt to account for the potentially adverse effects that eliminating some CUE bus stops could have on commercial, recreational and shopping trips by residents. These trips are important for households in the service area who do not have private vehicles. Surveys of CUE bus riders could help to address these limitations and ultimately provide a more detailed assessment of the potential tradeoffs of eliminating some CUE bus stops.

References


Litman, T. 2009. Transportation cost and benefit analysis: Techniques, estimates and Implications. Victoria Transport Policy Institute, Victoria, BC.


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Abstract

This paper examines policies and strategies governing the operations of bus lanes in major congested urban centers where the bus lanes do not completely exclude other uses. The two key questions addressed are:

1. What is the scope of the priority use granted to buses? When is bus priority in effect, and what other users may share the lanes during these times?
2. How are the lanes enforced?

To answer these questions, the study developed detailed cases on management strategies in seven cities that currently have shared-use bus priority lanes: Los Angeles, London, New York City, Paris, San Francisco, Seoul, and Sydney. Through the case studies, the paper examines the range of practices in use and highlights innovative ones that may contribute to bus lane success.

Introduction

In recent years, there has been a wave of interest and innovation in strategies to make bus operations more efficient and effective. Amid global interest over fully-segregated transitways such as Bogotá’s TransMilenio, the shared-use bus priority lane has often been overlooked. Yet, because it is far more flexible than its higher-
end cousins, it can be a practical solution in a wide range of contexts, particularly in urban centers where limited street capacities make it impractical to segregate lanes solely for transit use.

This paper examines policies governing the operations of bus priority lanes in congested urban centers. The two key questions addressed in this paper are:

1. What is the scope of the priority use granted to buses? When is bus priority in effect, and what other users may share the lanes during these times?
2. How are the lanes enforced?

In a comprehensive examination of bus priority lanes in seven international cities, the authors documented a range of institutional, design, and operational practices, as well as innovative practices that contribute to bus lane success. (For additional detail beyond that in this paper, see Agrawal, Goldman, and Hannaford 2012.)

**Previous Studies on Bus Lanes**

The present study builds upon the existing research by providing a management perspective unusual in the literature, which tends to focus on physical design.

The literature on bus priority treatments dates back to the mid-1950s, though the first comprehensive studies appeared in the 1970s (Levinson et al. 1973; Levinson, Adams, and Hoey 1975; NATO 1976). More recently, there has been a renewed interest in bus lanes, especially as they relate to bus rapid transit (BRT) systems (Levinson et al. 2003; Danaher 2010; Deng and Nelson 2010). Another strand of recent research has looked at proposals for “intermittent” bus lanes that prohibit general traffic only when buses are present (Viegas and Lu 2001; Eichler and Deganzo 2006; Viegas et al. 2007; Currie and Lai 2008). There have also been a few examinations of the policy processes that lead to the development of bus priority systems (Miller and Buckley 2001; Matsumoto 2006).

Comprehensive assessments of the effectiveness of bus lanes have been scarce. City governments’ own evaluation studies usually focus on determining whether a recently-installed bus lane should remain in place. Because traffic conditions and street geometry vary so significantly from place to place, and other bus priority treatments and traffic mitigation strategies are often implemented at the same time as bus lanes, it is difficult to draw generalizable conclusions from these studies. Nonetheless, there have been several attempts to distill the impacts of bus lanes and other priority strategies (St. Jacques and Levinson 1997; St. Jacques and

**Study Methodology**

The primary study method was the development of case studies for Los Angeles, London, New York City, Paris, San Francisco, Seoul, and Sydney. These cities were chosen because they have networks of bus priority lanes running through congested, mixed-use urban districts and policies allowing other vehicles to share the lanes on a limited basis. The cities were also chosen to reflect a diverse range of policy and design choices.

For each case, we reviewed available government reports, academic studies, conference papers, newspaper archives, websites, and local and state laws and regulations, and conducted interviews with local professionals working on bus lane planning, operations, and enforcement. Each case was reviewed by at least one person with expertise on bus lanes in that city. In total, 43 experts either were interviewed by the authors or reviewed a draft and provided comments. In Los Angeles, New York City, Paris, San Francisco, and Sydney, the research team photographed the lanes and observed them in operation.

**Case Studies**

The next section discusses the seven case study cities, summarizing notable features about the bus lane system in each. Two following sections summarize key findings from the case studies on the two research questions. A concluding section summarizes the findings.

**Overview**

The following section presents a very brief overview of each city’s bus lane system, highlighting some notable features. Table 1 presents the date each system was founded and the length of the network at the time the study research was completed.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>London</th>
<th>LA</th>
<th>NYC</th>
<th>Paris</th>
<th>SF</th>
<th>Seoul</th>
<th>Sydney</th>
</tr>
</thead>
<tbody>
<tr>
<td>Miles of bus priority networks*</td>
<td>177</td>
<td>4</td>
<td>50</td>
<td>118</td>
<td>18</td>
<td>127</td>
<td>14</td>
</tr>
</tbody>
</table>

*Excludes fully-separated transitways.

Sources: See case studies in the appendices of Agrawal, Goldman, and Hannaford 2012.
London has developed one of the most comprehensive systems of bus priority lanes in the world during the past 40 years. As of 2009, London’s bus priority network included 1,200 segments and extended about 177 miles. London has an unusually decentralized approach to bus lane administration, which has been led by the metropolitan government on a network of key arterials, but by local authorities elsewhere. London’s bus lane program is also notable for its comprehensive approach to enforcement.

Los Angeles has a small bus priority network of only four miles. The network was first implemented in the 1970s and has been modified but not greatly expanded since. The longest segment of the network functions as an on-street extension of a fully-separated transitway that serves buses and carpools in the median of a freeway. From 2004 to 2007, the city also installed demonstration bus lanes along one mile of a congested stretch of Wilshire Boulevard. The lanes were removed due to some local opposition, but the city plans to reinstate them as part of a longer bus priority project in the corridor.

New York City has been developing a bus lane network for nearly five decades, during which time it has reinvented its system several times with new branding, design, and enforcement strategies. The network extends about 50 miles, mostly in short segments distributed around the city. Recently, New York has started to introduce comprehensively-planned, longer-distance bus priority lanes. New York is just beginning to implement camera-based enforcement of bus lanes on a limited basis.

Paris began developing a network of curbside bus lanes in the 1960s. Today, the system extends 118 miles. Over the past decade, bus lanes have been widened, and low granite curbs have been installed on about one-third of the bus lane network to physically segregate the lanes from general traffic (see Figure 1). These are not exclusive bus lanes because taxis, bicycles, and other vehicles may also use them, but they have a greater degree of separation than can be achieved by paint alone.

San Francisco has 14 miles of bus priority lanes. To improve enforcement, the city has recently experimented with new relationships with the police and a pilot camera enforcement program. To a greater extent than any of the other case study cities, San Francisco’s bus priority lanes are offset from the curb to allow other vehicles to access the curb lane throughout the day (see Figure 2).
Figure 1. Raised curb delineating bus lane and marked delivery parking spot within a bus lane (Paris)

Figure 2. Parking bay to the right side of a San Francisco bus lane
Seoul developed a comprehensive system of curbside bus lanes beginning in the 1980s. Since 2004, it has upgraded many of its bus lane corridors to operate in the median, adapting its surface transit system to keep pace with the city’s rapid population and economic growth. However, its median bus lanes retain some shared use, since other vehicles may use the lanes to make left turns in some locations.

Sydney is the smallest of the cities examined here and has the newest bus priority lane network. It is unique for its reliance on fully-automated camera-based bus lane enforcement. Its bus priority lanes also have a range of different levels of access granted to other vehicles, including “transitways” intended for the exclusive use of buses (but not located in Inner Sydney), and “bus lanes” that facilitate buses but also allow taxis and turning vehicles as well.

**Access Policies**
Through access policies, bus priority lanes can strike a context-sensitive balance between the goal of unimpeded transit operations and the needs of other street space users. Use of this shared space can be allocated by time of day, or specific classes of vehicles can be allowed limited use of the lane.

In most cities, it proved surprisingly challenging to determine these access policies with precision. Municipal or other legal codes provide only a starting point for understanding these policies, since cities often have power to tailor rules on a location-specific basis. Street signage and pavement markings sometimes provided simplified representations of more complex regulations. Also, in some cases, police appeared to have their own informal criteria for administering bus lane rules that did not exactly match the legal codes or posted rules.

**Hours of Operation**
The hours of operation for bus lanes varied greatly, both between and within cities (see Table 2). The most common approach was for bus priority lane restrictions to be in force only during weekday peak periods, usually for two to four hours at a time. Outside of these hours, the lanes were used for general traffic, parking, or commercial deliveries. Among the cities examined here, peak-hour operations were prevalent in London, Los Angeles, New York, and Sydney, full-time lanes were more common in Paris and Seoul, and San Francisco had good numbers of both part-time and full-time lanes. Paris was the only city examined with no part-time bus lanes.
Standardizing hours of operation helps drivers learn more easily when they can and cannot use the lanes. However, allowing the hours to be tailored to local conditions allows better coordination with congestion and bus volumes, both of which can vary greatly from street to street within a city.

**Table 2. Bus Lane Hours of Operation**  
(Approximate Percent of Total Lane Miles)

<table>
<thead>
<tr>
<th>Hours of Operation</th>
<th>London</th>
<th>LA</th>
<th>NYC</th>
<th>Paris</th>
<th>SF</th>
<th>Seoul</th>
<th>Sydney</th>
</tr>
</thead>
<tbody>
<tr>
<td>24 hours, 7 days per week</td>
<td>29%</td>
<td>&lt;2%</td>
<td>100%</td>
<td>66%</td>
<td>44%</td>
<td>12%</td>
<td></td>
</tr>
<tr>
<td>Daytime hours, typically weekdays</td>
<td>25%</td>
<td>40%</td>
<td>11%</td>
<td>32%</td>
<td>18%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Peak periods only</td>
<td>46%</td>
<td>100%</td>
<td>58%</td>
<td>23%</td>
<td>24%</td>
<td>70%</td>
<td></td>
</tr>
</tbody>
</table>

In every case study city, certain users were permitted in the bus lanes under any circumstance, while other specified users were permitted into the bus lanes only for limited, designated purposes. The rules often differed in terms of the users and uses for which traveling and stopping or parking in the lanes was permitted. Table 3 provides an overview of users permitted in bus lanes in the cities studied.

The case study cities were divided on whether to allow bicycles to use bus lanes. London, Los Angeles, Paris, and Sydney permitted bicycles to travel in most bus lanes, except where particular locations posed safety concerns. In Paris, this was a deliberate policy to improve bicycle access. By contrast, New York, San Francisco, and Seoul did not allow bicycles to use bus lanes. Bike access to bus lanes is a matter of considerable debate in the street engineering community. Some see the two modes as fundamentally compatible because over longer distances, both travel at similar speeds. Others see them as incompatible because bicycles move at a constant speed while buses start and stop.
Table 3. Non-Bus Users Permitted in Bus Lanes

<table>
<thead>
<tr>
<th>Type of User</th>
<th>London</th>
<th>LA</th>
<th>NYC</th>
<th>Paris</th>
<th>SF</th>
<th>Seoul</th>
<th>Sydney</th>
</tr>
</thead>
<tbody>
<tr>
<td>Users permitted at all times</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bicycle</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td></td>
<td></td>
<td>•</td>
<td>•</td>
</tr>
<tr>
<td>Motorcycle/moped</td>
<td>•</td>
<td></td>
<td></td>
<td>•</td>
<td></td>
<td>•</td>
<td>•</td>
</tr>
<tr>
<td>Taxi</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
</tr>
<tr>
<td>Municipal or utility vehicle on business</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
</tr>
<tr>
<td>Disabled-placard holder</td>
<td>•</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>•</td>
<td>•</td>
</tr>
<tr>
<td>Carpool</td>
<td></td>
<td></td>
<td></td>
<td>6+</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Users permitted to travel in bus lanes under certain conditions</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Any vehicle turning at nearest intersection (no more than 1 block)</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
</tr>
<tr>
<td>Any vehicle entering/exiting driveway or curb parking along block</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
</tr>
<tr>
<td>Users permitted to stop in bus lanes</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Taxi loading/unloading</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
</tr>
<tr>
<td>Any vehicle loading/unloading</td>
<td>•</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>•</td>
<td>•</td>
</tr>
<tr>
<td>Disabled-placard holder loading/unloading</td>
<td>•</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>•</td>
</tr>
<tr>
<td>Delivery vehicle, for loading/unloading, as posted</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
<td>•</td>
</tr>
</tbody>
</table>

* = Yes, for at least some lanes in the system.
Empty cell indicates either “no” or “don’t know.”
Sources: See case studies in the appendices of Agrawal, Goldman, and Hannaford 2012.

Use of bus lanes by motorcyclists and other motorized two-wheel vehicles is also a contentious issue in several cities. Until recently, only Sydney permitted motorcyclists to travel in bus lanes as regular policy. Interviewees from two cities mentioned that the police do not prioritize ticketing motorcyclists in bus lanes, even though they are illegal users. In London, Transport for London (TfL) conducted two trials to see if motorcyclists could be integrated into bus lanes safely and with meaningful time-savings benefits, and in 2012, the Agency legalized motorcycle use for most of its bus network.

All of the case study cities except New York and Seoul permitted taxis to travel in bus lanes. This policy is often based on the premise that taxis are a critical mode supporting residents who choose to live car-free or to use cars minimally. Similarly,
most of the cities allowed bus lane use by jitneys, or privately-owned multi-passen-
ger vehicles that serve a regular route but are not contracted service providers for
a publicly-owned or managed transit system.

Four of the seven case study cities explicitly permitted some travel in bus lanes
by government-owned vehicles and/or utility vehicles such as refuse collection
vehicles, city-owned cars used for official city business, and mail delivery trucks.
All of the cities allowed emergency vehicles to use the bus lanes, although some
cities specified that these vehicles must be traveling to an actual emergency. Paris
allowed doctors traveling to visit a patient to use the lanes.

**Access to Bus Lanes for Designated Purposes**

All the case study cities allow a private vehicle to travel in a bus priority lane for
some maximum distance (up to one block) to access a driveway located in that
block. And in all the cities except Paris, any vehicle could normally drive in a bus
lane for a short distance in order to make a turn at the nearest approaching inter-
section. For example, in San Francisco, a vehicle may travel up to one block in a
bus lane for the purposes of turning, while in New York, no maximum distance is
specified, as long as the vehicle makes its first legal right turn. Finally, in New York
City, Seoul, and Sydney, any vehicle may temporarily travel in a bus lane to avoid
an obstacle.

All of the case cities permitted taxis to stop in bus lanes to load or unload passen-
gers, and several cities granted the same right to private-hire vehicles like charter
buses or limousines. London permitted vehicles bearing “disabled” placards to stop
in a bus lane to load or unload passengers, and New York, uniquely, granted the
same privilege to any private vehicle.

Three of the cities allowed delivery vehicles to stop in bus lanes for loading and
unloading, at least during certain hours or in certain locations. Paris had perhaps
the most sophisticated such system, with special loading spots that permit buses
to pass stopped delivery vehicles (see Figure 2). These designated loading areas
extend part way into the sidewalk and part way into the bus lane. Delivery vehicles
could use these spots in off-peak hours, which are indicated on street signs. New
York, for its part, limited some of its curbside bus lanes to peak-hour operations in
order to permit commercial deliveries during mid-day hours.
Enforcement
Effective enforcement is a perennial challenge to the effectiveness of bus lanes. If drivers come to expect that there is a high probability they will get caught for driving or parking in a bus lane, they will generally heed the rules. But if they come to expect a low risk of getting caught, some will begin to venture into the lane, preventing the lane from providing legal users with the intended free-flow travel.

Laws and Penalties
The legal systems of the case study cities and counties differ, but a key distinction is the treatment of a bus lane violation as an infraction versus as an administrative violation. The distinction is important because although the penalties for infractions can be more severe, they are far more difficult to administer and, if not matters of public safety, they are often unenforced.

In most of the case study cities, driving in a bus lane was considered to be a moving violation. Moving violations, or violations of laws concerning the operation of vehicles, are typically considered infractions or misdemeanors. In these cases, charges are usually filed by a sworn law enforcement officer directly against the operator of a vehicle, and the driver is subject to a hearing in court. In addition to fines, such offenses can result in penalties against the driver’s license to operate a vehicle, or even in jail time.

In contrast, the laws concerning the parking of vehicles (including parking illegally in a bus lane) are generally considered administrative violations of the law. Parking tickets are often administrative notices that can be issued by agents who are not fully-sworn police officers. These tickets do not require identification of the individual who parked the vehicle illegally and are instead issued to the vehicle’s registered owner. The tickets result in an automatic fine without the need for a court hearing, although the recipient of a parking ticket can typically request a hearing before a judge.

In some cities, there have been efforts to enable citations for moving violations in bus lanes to be handled as administrative violations so that they may be issued by automated cameras or traffic control agents who are not police officers, and to reduce the evidentiary and procedural burden of enforcing them. London, Paris, San Francisco, and Seoul had laws that enable enforcement by traffic agents or, in some cases, by camera. In Los Angeles and New York, bus lane moving violations remained infractions. New York had authorized camera-based enforcement on some new bus lanes, and in these cases somewhat lower civil fines were issued.
Sydney used a hybrid approach. Bus lane moving violations were enforced either by police patrols or else by the state transportation agency using automated cameras. The violations were handled administratively (without court proceedings) but could result in points being added to a vehicle owner’s license. To avoid these points, the onus was on the vehicle owner to prove that somebody else was operating the vehicle.

**Patrol-Based Enforcement**

Historically, it has been difficult for the police to sustain bus lane enforcement efforts amid the many other issues pressing for their attention. Cities have tried a variety of methods to maintain a police focus on bus lane enforcement. In London, the municipal transportation agency contracted with the police department to provide services related to safety, maintenance of traffic flow, enforcement of bus lanes, and other objectives, and a dedicated command unit was established to carry out the agreement. In San Francisco, the police established a dedicated unit with a focus on bus lane enforcement and other traffic issues. This unit operates under the supervision of the transportation agency.

A common alternative to continuous enforcement of bus lanes is “sweep” or “blitz” style enforcement, where intensive enforcement activities are conducted periodically for brief periods. Because of their high resource requirements, these efforts cannot be sustained for long. They can help raise public awareness of the law, but have little residual effect if some visible enforcement effort is not maintained between sweeps. Paris and Los Angeles have used such brief but intensive enforcement campaigns when first introducing bus lanes.

All of the case study cities relied primarily on civilian enforcement agents to issue violations for parking in a bus lane, usually as part of units that enforce parking regulations more generally. In most, these were employees of the city’s transportation agency, a separate parking agency, or some other administrative unit. Police agencies in London, New York, and Paris had dedicated units for parking enforcement consisting of non-sworn (civilian) employees. New York and Paris also empowered certain transit agency employees to issue parking tickets for bus lane violations. Additional parking enforcement powers were held by some sub-municipal entities, including London’s boroughs and Seoul’s Gu (administrative districts).

**Camera-Based Enforcement**

Automated, camera-based enforcement of bus lanes provides an attractive alternative to patrol-based enforcement strategies. There are no gaps in enforcement
as long as the equipment is working properly, and the high detection rate provides a strong deterrent. Also, while cameras do not eliminate the need to commit personnel resources to the overall enforcement effort, the approach largely shifts personnel time to a more manageable back-office operation.

However, camera-based enforcement has a number of political, legal, and administrative challenges, and it has only been implemented widely in a few cities. In places where driving in bus lanes is treated as an infraction, it can be difficult for camera-based systems to meet evidentiary standards (e.g. proof of the driver’s identity). Bus lane enforcement cameras also face the same public concerns that make speed and red light cameras unpopular: the potential for privacy violations, questions about reliability, perceptions that the cameras are implemented only to generate revenue, and concerns that drivers trying to avoid fines will drive unsafely.

Stationary cameras have been implemented most extensively in London and have also been adopted in New York, Paris, Seoul, and Sydney. London and Paris both experimented with bus-mounted cameras, but neither found the technology to be practical. New York, San Francisco, and Seoul also had bus-mounted camera trials planned or underway. Some cities experimented with portable cameras that can be deployed to problem areas as needed: “smart car patrols” in London and mobile camera units in Seoul. Of the case study cities, only Los Angeles had not implemented any camera-based bus lane enforcement.

The technologies used for bus lane cameras varied from city to city and were evolving rapidly. In most of the cities, agents reviewed raw footage or electronically-selected excerpts to identify cases where violations have occurred and should be prosecuted. Sydney relied on computer processing of high-resolution photos taken at intervals along the bus lanes and issued violation notices automatically to vehicles detected by consecutive cameras.

Table 4 summarizes camera-based enforcement in the cities studied.

**Passive Enforcement**

One passive enforcement strategy that some cities had adopted is “offset” or “interior” bus lane alignments, which reserve space for a general travel or stopping lane along the curb. These have long been used in San Francisco and were becoming widely used in London, New York, Paris, and Sydney. This approach preserves curb access for parking, loading, and turns, while reducing the degree to which these activities conflict with buses. These types of lanes are often said to be “self-enforcing” because their location away from the curb makes them much less prone to
Table 4. Camera-Based Enforcement

<table>
<thead>
<tr>
<th>Feature</th>
<th>London</th>
<th>LA</th>
<th>NYC</th>
<th>Paris</th>
<th>SF</th>
<th>Seoul</th>
<th>Sydney</th>
</tr>
</thead>
<tbody>
<tr>
<td>Camera-based enforcement employed</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td>P</td>
</tr>
<tr>
<td>Type of laws enforced by camera</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moving violations</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td>P</td>
</tr>
<tr>
<td>Parking/stopping violations</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td>P</td>
</tr>
<tr>
<td>Administrating agency</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Police department</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td>P</td>
</tr>
<tr>
<td>Transit operator/other municipal agency</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td>P</td>
</tr>
<tr>
<td>Camera placement</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>On-board buses</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td>P</td>
</tr>
<tr>
<td>Stationary (along street)</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td>P</td>
</tr>
<tr>
<td>Mobile units, patrol vehicles</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td>P</td>
</tr>
<tr>
<td>Analysis of images to verify violations</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Automated</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td>P</td>
</tr>
<tr>
<td>Manual</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td>P</td>
<td>P</td>
</tr>
</tbody>
</table>

P = Pilot testing  
Sources: See case studies in the appendices of Agrawal, Goldman, and Hannaford 2012.

being blocked by stopped vehicles. A second passive enforcement strategy is Paris’s use of low curbs separating bus lanes from general traffic. These discourage general traffic from entering the bus lane, without preventing all non-bus users outright.

Conclusion
This survey examined the policies used to manage bus priority lanes in cities with a broad range of political cultures and institutional environments. Overall, it found a wide array of different strategies in use, rather than convergence on a single universal set of strategies.

In general, bus priority lanes seek to improve bus speeds while addressing the access and mobility needs of other transportation system users. This balance can be achieved in multiple ways, such as allowing other vehicles to access the bus lane under defined conditions, scheduling different uses for the lane during different times of day, and positioning the bus lane to change the mix of users affected by the bus lane’s presence. In general, nearly every city studied allowed all vehicles to
use curbside bus priority lanes to make right turns (left turns in the UK and Australia) and to access driveways on a given block. Taxis were universally allowed to use the lanes to pick up and discharge passengers. Several cities authorized bicycles and taxis to drive in a bus lane as well. Other exemptions were more unusual. As for hours of bus priority, while bus lanes operated around the clock in a few of the cities, in most they only operated during peak hours of public transit use.

With respect to bus lane enforcement, cities are typically constrained by their political and legal systems to a limited number of enforcement options available. Enforcement of laws concerning the operation of motor vehicles is usually a police responsibility, and granting police powers to a civilian transportation agency is not possible. States and cities had dealt with this challenge in various ways. Some had laws classifying bus lane violations as civil infractions that can be enforced by civilian agents and/or by automated cameras. Others had developed contractual or supervisory relationships between police and transportation agencies to ensure that there were personnel directly responsible for bus lane enforcement. An additional approach was to use design strategies like physical barriers or offset bus lanes that reduce the need for enforcement.

**Acknowledgements**

The authors thank the Mineta Transportation Institute at San José State University for funding this research. In addition, we offer deep thanks to the many people who contributed to this study, including Alejandro Blei, Harika Boga, Jennifer Donlon, Dennis Freeman, Jeff Gerlach, Cameron Gordon, Roland Jezeck, Camille Kamga, Seon Joo Kim, Herbert S. Levinson, Robert Paaswell, Jose Pillich, Mark Seaman, Arjun Thyagarajan, and the many professionals who volunteered their time as interviewees and reviewers of draft cases. All errors or omissions are the responsibility of the author.

**References**


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The Modern Streetcar in the U.S.: An Examination of Its Ridership, Performance, and Function as a Public Transportation Mode

Jeffrey Brown, Florida State University

Abstract

Seven U.S. cities reported operating streetcar service to the National Transit Database in 2012, and many other cities are building or planning streetcar investments. Yet despite the increased popularity of streetcar investments, there is a lack of information about how these investments function as transportation modes, as opposed to urban development tools. This paper examines the streetcar as a public transit mode by examining ridership, service, service productivity, cost effectiveness, and other indicators of the streetcar’s performance and function in the carriage of transit passengers. There is considerable variation in all of these measures, with the variability a function of the different environments in which streetcars operate, the different roles they play in the local transit system, and differences in the operating characteristics of the streetcars themselves. Among the cases, Portland’s streetcar emerges as a strong performer, Little Rock’s and Tampa’s streetcars as relatively poor performers, and the other streetcars have mixed performance results.

Introduction

The streetcar, an urban transportation mode whose golden age was thought to have been the period from roughly the 1890s to the 1910s, has made a remarkable resurgence in the United States in recent years. As of September 2012, transit
agencies in eight cities reported operating streetcar modes in regular, year-round revenue service to the Federal Transit Administration (FTA): Little Rock, Memphis, New Orleans, Philadelphia, Portland, Seattle, Tacoma, and Tampa (Federal Transit Administration [FTA] 2012). Boston and San Francisco also operate streetcars on their Ashmont-Mattapan and F lines, respectively, although their statistics are folded into their light rail transit (LRT) services in the National Transit Database (NTD) statistics. Several other cities, from Kenosha, Wisconsin, to San Pedro, California, operate seasonal or weekend-only streetcar lines. Several cities report streetcar projects under construction, while more than 40 others have projects in various stages of planning. The streetcar’s apparent rebirth after decades of what had appeared to have been technological obsolescence is truly remarkable.

There are many reasons for the streetcar’s return to the urban transportation scene, although economic development and the availability of federal capital funding under the New Starts/Small Starts program are the most frequently cited rationales for its reemergence (Scheib 2012; Transit Cooperative Research Program [TCRP] 2010). Both streetcar supporters and streetcar critics point to Portland, Oregon, to support their assertions about the streetcar’s urban development effects. Supporters point to hundreds of millions of dollars in commercial development and redevelopment, particularly in the city’s Pearl District (Hovee and Gustafson 2012; TCRP 2010), which they argue can be traced directly to Portland’s decision to build a streetcar; skeptics argue that public financial incentives and regulatory inducements were more important than the streetcar itself in attracting development to these locations (O’Toole 2012; Scheib 2012). The real explanation for Portland’s apparent redevelopment success is most likely a combination of these factors, combined with a desirable location and a vibrant local real estate market. The relative abundance of federal capital funding under the Small Starts program for streetcar development and the relative lack of federal funding for more expensive conventional LRT development has also encouraged cities to look to streetcars instead of other rail modes when they consider making significant fixed transit investments. Officials in the Obama Administration have been especially strong promoters of streetcar development.

This paper does not attempt to explain the streetcar’s role in the urban development and redevelopment process, nor does it offer suggestions for the future of federal transit capital grants policy. Instead, it sets a much narrower, but still important, task—it explores a much-neglected aspect of the streetcar’s rebirth in the modern metropolis, namely its role as a means of transportation situated within a
local public transit system. The streetcar is fundamentally a transportation technology, but the scholarly and practitioner literature that considers the streetcar as primarily a public transportation mode, as opposed to an urban development tool, is remarkably sparse. Indeed, the only published work this author could find that took a ridership and operations approach to examining streetcars was a graduate student client project for a transit agency that examined four streetcar cities in the context of an alternatives analysis dealing with streetcars, light rail transit, and French tramways (Transit Alternatives Studio Members 2011). The author found that streetcars were not as efficient or cost-effective in carrying riders than either of the other two rail technologies. While a very worthy reference, the work takes a necessarily circumscribed approach to the streetcar discussion by virtue of its broader topical focus on an array of rail modes. This paper is an attempt to begin to remedy the lack of ridership and operation-oriented empirical work on streetcars. It does so by examining the streetcar in terms of its ridership, its service performance statistics, and its level of integration with and role within the larger transit system in the community. The paper explores the streetcar’s performance and role as a public transportation mode by looking at seven of the eight cities that report operating year-round, regular revenue streetcar service in the NTD. These seven cities include six cities whose streetcar lines are 20 years old or newer (Little Rock, Memphis, Portland, Seattle, Tacoma, and Tampa) and one city (New Orleans) whose lines predate the streetcar’s modern reemergence. Among these seven cities, there is significant variation in streetcar ridership and performance, with the variation a function of both the way the streetcar is either integrated (or not) with the rest of the transit system, its operating characteristics, and the nature of the built environment within which the streetcar operates. The paper closes with lessons from these cases and directions for future research.

### Seven Streetcar Cases

Seven cities were selected for inclusion in the analysis, by first considering all the transit agencies that reported operating a streetcar mode to the NTD and then narrowing this list based on the regularity of the service being operated and the availability of streetcar data preceding the 2012 reporting year when the NTD separated streetcar (mode code SR) from light rail (mode code LR) service in the database. These criteria led to the exclusion of two of the nine cities that reported streetcar service to the NTD in 2012: Kenosha on the basis of its seasonal service provision and Philadelphia due to data availability concerns, as streetcar data are not separated from the Southeastern Pennsylvania Transportation Author-
ity’s light rail services prior to the 2012 NTD reporting year. The research did not consider Boston or San Francisco because the Massachusetts Bay Transportation Authority and San Francisco Municipal Transportation Agency continue to report their streetcar line statistics to the NTD as part of their light rail statistics. Little Rock, Memphis, New Orleans, Portland, Seattle, Tacoma, and Tampa emerged as the case study cities for the investigation.

The investigation began with several questions in mind. First, what are the basic characteristics of the streetcars and how do they differ? Second, how many riders do they carry, how productively, and at what cost? And, third, where do the streetcars fit in, if at all, with the rest of the transit system? A combination of ridership, service, and cost data were obtained from the NTD, plus internal data were obtained from each agency to address each of these questions. Before answering these questions, each of the seven streetcar cases is briefly described below.

**Little Rock**

Little Rock’s streetcar, River Rail, connects the downtowns of Little Rock and North Little Rock using an alignment that is mixed traffic except for a dedicated lane on a bridge over the Arkansas River (Central Arkansas Transit Authority 2012; Smatlak 2012). The streetcar consists of a Blue line that connects the two downtowns and a Green line that operates through downtown Little Rock. The original line opened in 2004, and an extension opened in 2007. The River Rail functions as a circulator connecting major downtown destinations, including the Clinton Presidential Library.

**Memphis**

Memphis’s streetcar, the Trolley, consists of the Main Street line (opened in 1993), the Riverfront line (opened in 1997), and the Madison Avenue line (opened in 2004) (Memphis Area Transit Authority 2012; Smatlak 2012). The first two lines operate in the downtown area and along the Mississippi River, with the Main Street line operating in mixed traffic, except for the segment through the Main Street pedestrian mall, and the Riverfront line operating on a dedicated, double-track railroad right-of-way near the river. The Madison Avenue line operates in mixed traffic. The older lines connect important destinations in the downtown area, with the Riverfront line functioning as a belt-like circulator through the downtown area. The Madison Avenue line connects the downtown lines with important destinations to the east, include major medical facilities.
New Orleans
New Orleans operates three streetcar lines, one of which (Canal Street) has two branches (New Orleans Regional Transportation Authority 2012; Smatlak 2012). The oldest line, St. Charles, dates to the late 19th century. The line operates primarily in a center median, except for a short distance in mixed-traffic service. This line has more than 50 stops and is operated 24 hours a day, 7 days a week. The Riverfront line, which dates back to 1988, uses a traditional railroad right-of-way, serving major tourist-related destinations including areas near the French Quarter and commercial development in the Warehouse and Riverfront districts. The Canal Street line, restored to streetcar service in 1999, operates in a center median and features stops every two blocks. Much of the line operates through the downtown area. The branch lines include some mixed-traffic operation.

Portland
Portland now operates both a north-south and a central loop line (just opened), but this study focuses on the original north-south line (opened in 2001) that connects the Pearl District, Downtown, and Portland State University and operates as a one-way circulator loop primarily on parallel city streets (Portland Streetcar, Inc. 2012a; Smatlak 2012). The area consists of very high-density development, with many observers pointing to the streetcar as an important contributor to recent redevelopment activity. The recently-opened central loop line operates on both sides of the Willamette River and provides links between the downtown core and the eastside Lloyd Center area and the eastside central industrial district.

Seattle
Seattle’s South Lake Union streetcar (opened in 2007) connects the South Lake Union neighborhood to downtown via Westlake and Terry Avenues (Seattle Streetcar 2012; Smatlak 2012). There has been much employment growth in this corridor in recent years. The streetcar operates both in mixed traffic and in a dedicated lane through portions of the alignment.

Tacoma
Tacoma’s streetcar, Tacoma Link, operates in the downtown area and as a feeder to the longer-distance bus and regional rail services at its terminal station (Sound Transit 2012; Smatlak 2012). The line operates in a combination of center-median and reserved-lane alignments over its short alignment. The Tacoma streetcar is a fare-fee system. The transit agency brands the line as light rail transit, but it operates more like a streetcar and is identified as a streetcar in the NTD.
**Tampa**

Tampa’s TECO streetcar line, opened in 2002, connects the historic Ybor City neighborhood with a number of other tourist-focused destinations (Convention Center, Channelside) in the downtown area (TECO Line Streetcar System 2012). The vehicles operate in segregated rights-of-way on city streets. The streetcar’s late hours of operation make this a non-commuter-oriented, tourist-focused operation.

**Basic Streetcar Operating and Service Characteristics**

Table 1 reports basic streetcar operating and service statistics for the seven cities. The seven streetcar systems are either operated directly or under contract by the primary transit agency in each city. Five of the seven streetcars have opened since 2001, with New Orleans having the oldest system, dating back to the late 19th century. Most of the streetcar alignments are short, with Memphis and New Orleans having longer alignments because they operate multiple streetcar lines. Streetcar operating speeds (vehicle revenue miles divided by vehicle revenue hours, or miles per hour during revenue service) are generally slow, with the highest speeds found in Tacoma, Memphis, New Orleans, and Portland. All of the streetcars operate at speeds slower than the average motor bus in the local transit system, with most streetcar speeds less than half the average bus speed (the slowest bus speeds among the seven cities are in Portland, with an average of 11.8 miles per hour, calculated as total bus revenue miles divided by total bus revenue hours) (FTA 2012). The various streetcar lines have a wide variation in the number of stops, with stop spacing ranging between 0.10 miles and 0.25 miles across the seven cities, but there appears to be little correlation between stop spacing and operating speeds. The two cities with the closest stop spacing (Portland and New Orleans) are not the cities with the slowest streetcars; instead, they rank third and fourth fastest among the seven streetcar cities.

The streetcar fares in Seattle and Tampa are higher than the regular bus fares, while the fares in Little Rock and Memphis are lower than the regular bus fare. The fares in Portland and New Orleans are identical to the bus fare. Prior to September 1, 2012, Portland operated a fare-free zone on its streetcars in the downtown; thus, the statistical data on ridership and service reflect the earlier period with the fare-free zone in place. The streetcar in Tacoma, Tacoma Link, still operates fare-free service. In addition to operating within the downtown, this streetcar serves as a feeder to longer-distance bus and rail transit services that operate under a zonal fare system based on trip distance.
Table 1. Characteristics of U.S. Streetcars Operated in Regular Revenue Service

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Little Rock</th>
<th>Memphis</th>
<th>New Orleans</th>
<th>Portland¹</th>
<th>Seattle</th>
<th>Tacoma²</th>
<th>Tampa</th>
</tr>
</thead>
<tbody>
<tr>
<td>Management (agency)</td>
<td>Central Arkansas Transit Authority</td>
<td>Memphis Area Transit Authority</td>
<td>New Orleans Regional Transit Authority</td>
<td>Portland Streetcar, Inc.³</td>
<td>King County Metro</td>
<td>Sound Transit</td>
<td>Hillsborough Area Regional Transit Authority</td>
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<tr>
<td>Metro area population (2010)</td>
<td>699,757</td>
<td>1,316,100</td>
<td>1,167,764</td>
<td>2,226,009</td>
<td>3,439,809</td>
<td>3,439,809</td>
<td>2,783,243</td>
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<tr>
<td>Capital cost</td>
<td>$27,200,000</td>
<td>$104,000,000</td>
<td>n/a</td>
<td>$103,150,000</td>
<td>$52,100,000</td>
<td>$81,000,000</td>
<td>$32,000,000</td>
</tr>
<tr>
<td>Length of route alignment (mi)</td>
<td>3.4 mi</td>
<td>7 mi</td>
<td>13.7 mi</td>
<td>4 mi</td>
<td>2.6 mi</td>
<td>1.6 mi</td>
<td>2.7 mi</td>
</tr>
<tr>
<td>Stops</td>
<td>15</td>
<td>35</td>
<td>100+</td>
<td>49</td>
<td>11</td>
<td>6</td>
<td>11</td>
</tr>
<tr>
<td>Avg. operating speed (mph)</td>
<td>4.43</td>
<td>7.56</td>
<td>6.81</td>
<td>5.68</td>
<td>5.37</td>
<td>7.73</td>
<td>5.38</td>
</tr>
<tr>
<td>(veh revenue mi/veh revenue hrs)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Streetcar fare (per single ride)</td>
<td>$1.00</td>
<td>$1.00</td>
<td>$1.25</td>
<td>$1.00</td>
<td>$2.50</td>
<td>No fare</td>
<td>$2.50</td>
</tr>
<tr>
<td>Transfer policy</td>
<td>Free transfer from bus to rail, not rail to bus</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>n.a.</td>
<td>Yes</td>
</tr>
<tr>
<td>Transfer rate</td>
<td>15%</td>
<td>Not yet available</td>
<td>More than 50%</td>
<td>Not yet available</td>
<td>Not yet available</td>
<td>29%</td>
<td>Not collected</td>
</tr>
<tr>
<td>Weekday peak headways</td>
<td>23–25 min</td>
<td>10–16 min</td>
<td>6–37 min</td>
<td>15–21 min</td>
<td>15 min</td>
<td>12 min</td>
<td>20 min</td>
</tr>
<tr>
<td>Weekday off–peak headways</td>
<td>23–25 min</td>
<td>10–16 min</td>
<td>8–37 min</td>
<td>14 min</td>
<td>15 min</td>
<td>12 –24 min</td>
<td>20 min</td>
</tr>
<tr>
<td>Weekday hours of operation</td>
<td>8:20/10 AM–10 PM/midnight</td>
<td>6 AM–approx. midnight</td>
<td>Varies by line, with one in continuous operation</td>
<td>5:30 AM–11:30 PM</td>
<td>6 AM–9 PM/11 PM</td>
<td>5 AM–10 PM</td>
<td>11 AM/noon–10 PM/2 AM</td>
</tr>
</tbody>
</table>

¹These are all the systems that report a streetcar (SR) mode to the NTD in 2012, excluding Keomsha, which operates on a seasonal basis.
³Portland Streetcar, Inc. is a non-profit organization set up as a partnership of the City of Portland and Tri-Met. The NTD counts it under Tri-Met for reporting purposes.
⁴The Tacoma-Link is classified as a streetcar in the National Transit Database.

Transfer policies reflect the agency’s view of the streetcar’s role in the larger transit system, in terms of whether it is viewed as a stand-alone service, as an integrated piece of the transit network, or something in between. Five of the seven cities permit fare-free transfers in either direction between bus and streetcar, while one city (Little Rock) allows bus riders (who pay a higher fare per ride) to transfer free to the streetcar but requires streetcar riders to pay an additional fare to use the bus. Tacoma’s streetcar is fare-free, so riders pay a fare when transferring to another transit service.

Transfer rates reflect the way riders actually use the streetcar in the context of the larger transit system, with higher transfer rates indicative of more service integration between the streetcars and the other transit modes. Differences in transfer rates correspond roughly to differences in the transfer policy. The highest reported transfer rates are found in New Orleans, which allows fare-free transfers across its transit modes, while the lowest reported transfer rates are found in Little Rock, which permits them in only one direction, from bus to streetcar. The other streetcars that function primarily as downtown circulators have reported transfer rates in between these two values. The fact that some systems, such as Hillsborough Area Regional Transit Authority in Tampa, do not even track transfer activity between the streetcar and other modes indicates that the agency does not view the streetcar as an integral part of its regular transit service. Streetcar headways and hours of operation are roughly comparable to those of the buses operated in the same geographic areas in each of the seven cities, with the exceptions of the Little Rock and Tampa, streetcars which begin service much later in the morning than the regular bus system.

**Key Performance Indicators**

Selected several key performance indicators were selected for gauging the performances of streetcars as modes of public transportation within their respective transit systems. The transfer rates noted earlier were one key measure of service integration, and operating speed is also a key service characteristic. The other key performance indicators include ridership, service, operating cost, and performance ratios such as ridership per unit of service (service productivity) and operating cost per ride (cost effectiveness). For ridership, both unlinked passenger trips (or boardings) and passenger miles were considered, when and where available. For service, both vehicle revenue hours and vehicle revenue miles were considered. For operating expense, total operating expense for the streetcar mode was included as defined in the NTD (FTA 2012). Finally, NTD variables were used to calculate the
streetcar’s share of total transit agency ridership and service to get a sense of the streetcar mode’s relative importance in the transit agency’s overall service delivery. These basic ridership, service, and cost data are available from the NTD for six of the agencies (FTA 2012; Florida Department of Transportation 2012). Prior to 2012, streetcar statistics were reported as part of the light rail mode in the NTD. For six of the seven cities, the streetcar would have been the only rail service reported under this mode code, so it is safe to assume that these statistics in the NTD referred to the streetcar and not another rail service. For the seventh city, Portland Streetcar, Inc., provided streetcar ridership and service data from 2008-2010, and for operating expense in 2010 (Portland Streetcar, Inc. 2012b; Portland Streetcar, Inc. 2012c). Due to the lack of operating expense data for other years from Portland, only 2010 operating cost data were considered in the study. Ridership data on a passenger mile basis were unavailable for Portland’s streetcar, hence its non-availability designation (n/a) in the relevant tables.

Tables 2, 3, and 4 report ridership statistics for the seven streetcar cities from 2008 until the most recent full reporting year. Table 2 shows that New Orleans, Seattle, and Tacoma have seen streetcar boardings increase in recent years, whereas Portland and Memphis have been relatively stable and Little Rock and Tampa have seen decreases. Table 3 reports ridership in terms of passenger miles, which gauges the length of passenger trip-making on the streetcar mode, and Table 4 reports average trip distances (passenger miles per unlinked passenger trip). The data in tables 3 and 4 are reported from 2008 to 2010, the last year for which passenger mile data are consistently available on a modal basis in the NTD. The key table here is Table 4, which indicates significant differences in the trip lengths served by the different streetcars. Much of this variability can be explained by differences in system extent and stop spacing, but some of the difference is also a function of the different ways that riders use these streetcars. The longer average trip lengths in New Orleans are indicative of a streetcar system that is used more like an LRT system, serving long-distance trips and indeed functioning as something like a transit system backbone (as is discussed later), while the short trip lengths in Seattle and Memphis point to the mode’s primary function as a downtown circulator mode or connector serving very short-distance trips. Because New Orleans is the oldest of the streetcar systems, with a pre-modern era streetcar network, it differs in many important respects from its modern peers.
### Table 2. Annual Ridership (Unlinked Passenger Trips) on U.S. Streetcars Operated in Regular Revenue Service (2008–2011)

<table>
<thead>
<tr>
<th>City</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
</tr>
</thead>
<tbody>
<tr>
<td>Little Rock</td>
<td>112,578</td>
<td>120,057</td>
<td>107,079</td>
<td>100,402</td>
</tr>
<tr>
<td>Memphis</td>
<td>1,060,410</td>
<td>1,158,904</td>
<td>1,092,605</td>
<td>1,157,425</td>
</tr>
<tr>
<td>New Orleans</td>
<td>4,708,139</td>
<td>4,715,163</td>
<td>5,931,758</td>
<td>6,602,396</td>
</tr>
<tr>
<td>Portland</td>
<td>3,880,079</td>
<td>3,785,553</td>
<td>3,950,860</td>
<td>3,838,398</td>
</tr>
<tr>
<td>Seattle</td>
<td>413,937</td>
<td>451,204</td>
<td>520,932</td>
<td>715,043</td>
</tr>
<tr>
<td>Tacoma</td>
<td>930,632</td>
<td>887,061</td>
<td>869,076</td>
<td>973,936</td>
</tr>
<tr>
<td>Tampa</td>
<td>455,940</td>
<td>466,536</td>
<td>479,967</td>
<td>386,423</td>
</tr>
</tbody>
</table>


### Table 3. Passenger Miles on U.S. Streetcars in Regular Revenue Service (2008–2010)

<table>
<thead>
<tr>
<th>City</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
</tr>
</thead>
<tbody>
<tr>
<td>Little Rock</td>
<td>206,572</td>
<td>183,751</td>
<td>165,718</td>
</tr>
<tr>
<td>Memphis</td>
<td>820,185</td>
<td>940,028</td>
<td>917,815</td>
</tr>
<tr>
<td>New Orleans</td>
<td>8,223,507</td>
<td>12,303,585</td>
<td>15,384,381</td>
</tr>
<tr>
<td>Portland</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>Seattle</td>
<td>378,221</td>
<td>414,617</td>
<td>471,587</td>
</tr>
<tr>
<td>Tacoma</td>
<td>919,371</td>
<td>880,476</td>
<td>871,189</td>
</tr>
<tr>
<td>Tampa</td>
<td>728,890</td>
<td>776,734</td>
<td>789,244</td>
</tr>
</tbody>
</table>


### Table 4. Average Trip Length (miles) on U.S. Streetcars in Regular Revenue Service (2008–2010)

<table>
<thead>
<tr>
<th>City</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
</tr>
</thead>
<tbody>
<tr>
<td>Little Rock</td>
<td>1.83</td>
<td>1.53</td>
<td>1.55</td>
</tr>
<tr>
<td>Memphis</td>
<td>0.77</td>
<td>0.81</td>
<td>0.84</td>
</tr>
<tr>
<td>New Orleans</td>
<td>1.75</td>
<td>2.61</td>
<td>2.59</td>
</tr>
<tr>
<td>Portland</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>Seattle</td>
<td>0.91</td>
<td>0.92</td>
<td>0.91</td>
</tr>
<tr>
<td>Tacoma</td>
<td>0.99</td>
<td>0.99</td>
<td>1.00</td>
</tr>
<tr>
<td>Tampa</td>
<td>1.60</td>
<td>1.66</td>
<td>1.64</td>
</tr>
</tbody>
</table>
Table 5 reports the streetcar revenue hours and revenue miles of service operated in each city from 2008 to 2011. The table shows that the amount of service being operated has either been stable or in modest decline in most cities. Little Rock, New Orleans, and Seattle offered more service in 2011 than they provided in 2008, but, in two of those three cases, the amount of service they provided was less in 2011 than it was in 2010. Thus, it is difficult to detect any trend related to the amount of service provided.

Table 5. Annual Service on U.S. Streetcars Operated in Regular Revenue Service (2008–2011)

<table>
<thead>
<tr>
<th>City</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicle Revenue Miles</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Little Rock</td>
<td>38,381</td>
<td>37,696</td>
<td>52,687</td>
<td>42,063</td>
</tr>
<tr>
<td>Memphis</td>
<td>412,765</td>
<td>362,410</td>
<td>298,763</td>
<td>294,536</td>
</tr>
<tr>
<td>New Orleans</td>
<td>756,815</td>
<td>816,890</td>
<td>947,790</td>
<td>926,132</td>
</tr>
<tr>
<td>Portland</td>
<td>216,308</td>
<td>210,362</td>
<td>173,714</td>
<td>170,530</td>
</tr>
<tr>
<td>Seattle</td>
<td>56,904</td>
<td>60,150</td>
<td>59,964</td>
<td>61,727</td>
</tr>
<tr>
<td>Tacoma</td>
<td>94,189</td>
<td>89,427</td>
<td>90,195</td>
<td>82,565</td>
</tr>
<tr>
<td>Tampa</td>
<td>80,045</td>
<td>73,114</td>
<td>71,067</td>
<td>74,714</td>
</tr>
<tr>
<td>Vehicle Revenue Hours</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Little Rock</td>
<td>8,669</td>
<td>8,481</td>
<td>11,904</td>
<td>9,471</td>
</tr>
<tr>
<td>Memphis</td>
<td>59,210</td>
<td>56,790</td>
<td>48,797</td>
<td>39,612</td>
</tr>
<tr>
<td>New Orleans</td>
<td>94,461</td>
<td>102,439</td>
<td>122,586</td>
<td>127,472</td>
</tr>
<tr>
<td>Portland</td>
<td>38,047</td>
<td>37,001</td>
<td>30,555</td>
<td>29,995</td>
</tr>
<tr>
<td>Seattle</td>
<td>11,077</td>
<td>11,207</td>
<td>11,174</td>
<td>11,509</td>
</tr>
<tr>
<td>Tacoma</td>
<td>9,708</td>
<td>9,424</td>
<td>9,727</td>
<td>9,818</td>
</tr>
<tr>
<td>Tampa</td>
<td>15,713</td>
<td>14,246</td>
<td>13,805</td>
<td>14,077</td>
</tr>
</tbody>
</table>

Source (Portland): Benchmark Reliability Reports obtained from Portland Streetcar, Inc.

Table 6 reports the ridership associated with each hour or mile of service provided by the streetcar mode, from 2008 through 2011. This table is, thus, the first of the reported service performance, or service productivity, measures. Using the number of unlinked passenger trips per revenue mile (the upper panel of the table) as a performance indicator, the table indicates improved or stable service productiv-
ity from 2008 through the end of 2011 everywhere except Little Rock and Tampa. Using the number of unlinked passenger trips per revenue hour (the bottom panel of the table) as a performance indicator, and looking over the period from 2008 to 2011, the last complete year for which data are available, the table indicates increased service productivity in Memphis, Portland, and Seattle, whereas productivity has been relatively flat elsewhere. The biggest increase in productivity has occurred in Memphis (86% increase on a trips per mile basis and more than 100% increase on a trips per hour basis); Seattle has experienced a 60 percent increase in both of these productivity indicators. Service productivity increased in four other cities, at a more modest level, over the same time period, while service productivity actually declined in Tampa.


<table>
<thead>
<tr>
<th>City</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Unlinked Passenger Trips per Vehicle Revenue Mile</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Little Rock</td>
<td>2.93</td>
<td>3.18</td>
<td>2.03</td>
<td>2.39</td>
</tr>
<tr>
<td>Memphis</td>
<td>2.57</td>
<td>3.20</td>
<td>3.66</td>
<td>3.93</td>
</tr>
<tr>
<td>New Orleans</td>
<td>6.22</td>
<td>5.77</td>
<td>6.26</td>
<td>7.13</td>
</tr>
<tr>
<td>Portland</td>
<td>17.94</td>
<td>18.00</td>
<td>22.74</td>
<td>22.51</td>
</tr>
<tr>
<td>Seattle</td>
<td>7.27</td>
<td>7.50</td>
<td>8.69</td>
<td>11.58</td>
</tr>
<tr>
<td>Tacoma</td>
<td>9.88</td>
<td>9.92</td>
<td>9.64</td>
<td>11.80</td>
</tr>
<tr>
<td>Tampa</td>
<td>5.70</td>
<td>6.38</td>
<td>6.75</td>
<td>5.17</td>
</tr>
<tr>
<td><strong>Unlinked Passenger Trips per Vehicle Revenue Hour</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Little Rock</td>
<td>12.99</td>
<td>14.16</td>
<td>9.00</td>
<td>10.60</td>
</tr>
<tr>
<td>Memphis</td>
<td>17.91</td>
<td>20.41</td>
<td>22.39</td>
<td>29.22</td>
</tr>
<tr>
<td>New Orleans</td>
<td>49.84</td>
<td>46.03</td>
<td>48.39</td>
<td>51.79</td>
</tr>
<tr>
<td>Portland</td>
<td>101.98</td>
<td>102.31</td>
<td>129.30</td>
<td>127.97</td>
</tr>
<tr>
<td>Seattle</td>
<td>37.37</td>
<td>40.26</td>
<td>46.62</td>
<td>62.13</td>
</tr>
<tr>
<td>Tacoma</td>
<td>95.86</td>
<td>94.13</td>
<td>89.35</td>
<td>99.20</td>
</tr>
<tr>
<td>Tampa</td>
<td>29.02</td>
<td>32.75</td>
<td>34.77</td>
<td>27.45</td>
</tr>
</tbody>
</table>

A third service productivity is the load factor, or number of passenger miles per vehicle revenue mile. This indicator can be interpreted as the average number of passengers on a transit vehicle at a particular moment in time. Because passenger miles data are complete only through the end of 2010, the data presented in
Table 7 shows wide variation in load factor across the seven cities, with the highest values in New Orleans and Tampa, where streetcar riders tend to take longer trips, as noted earlier. The lowest load factors are found in Memphis and Little Rock, where average trip distances are relatively short and there are smaller numbers of trips per hour or per mile being carried on the streetcar. In both of these cases, there is significant excess passenger capacity on the streetcar lines. By contrast, streetcars in New Orleans are quite full, on average. The differences in load factors across the seven cities are, at least partially, due to the different urban settings in which the streetcars operate. New Orleans is a denser, more traditional urban environment with a larger transit-dependent population than the other cities, but the different roles the streetcar plays in these various cities—with the streetcars in New Orleans being better integrated with local bus services and operating at higher than average streetcar speeds—are undoubtedly also important explanations for the variation in load factor.

Table 7. Load Factor (Passenger Mile per Vehicle Revenue Mile) on U.S. Streetcars in Regular Revenue Service (2008–2010)

<table>
<thead>
<tr>
<th>City</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
</tr>
</thead>
<tbody>
<tr>
<td>Little Rock</td>
<td>5.38</td>
<td>4.87</td>
<td>3.15</td>
</tr>
<tr>
<td>Memphis</td>
<td>1.99</td>
<td>2.59</td>
<td>3.07</td>
</tr>
<tr>
<td>New Orleans</td>
<td>10.87</td>
<td>15.06</td>
<td>16.23</td>
</tr>
<tr>
<td>Portland</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>Seattle</td>
<td>6.65</td>
<td>6.89</td>
<td>7.86</td>
</tr>
<tr>
<td>Tacoma</td>
<td>9.76</td>
<td>9.85</td>
<td>9.66</td>
</tr>
<tr>
<td>Tampa</td>
<td>9.11</td>
<td>10.62</td>
<td>11.11</td>
</tr>
</tbody>
</table>

Table 8 reports streetcar operating expenses (in inflation-adjusted 2011 dollars) for both the modal total and on a per-unlinked-passenger-trip and per-passenger-mile basis for 2010, the most recent year for which data are available for the seven cases. The latter measures are the more instructive ones from a service performance perspective, because they are cost-effectiveness measures. The table indicates considerable variation in operating cost per unlinked passenger trip (UPT), with Portland at the low end and Tampa and Little Rock at the high end of the range. Streetcar service is much more cost-effective as a public transportation mode, on a per-trip basis, in Portland than in Tampa and Little Rock. The higher numbers of boardings per unit of service explain part of these differences in operating cost per passenger,
but so do differences in cost levels across the various cities. In 2010, operating cost per revenue hour (total operating cost divided by vehicle revenue hours) for the seven cities ranged from a low of $86 per hour in Little Rock to a high of $208 per hour in Seattle, although expressed on a per-revenue-mile basis (total operating cost divided by vehicle revenue miles), the ranges were from a low of $14 per mile in Memphis to $34 per mile in Tampa.

By comparison, operating cost per passenger trip by motor bus in the seven systems ranges from $3.95 per unlinked passenger trip in Portland to $7.29 per unlinked passenger trip in Tacoma, due to longer average trip lengths (Florida Department of Transportation 2012). In two cities (Little Rock and Tampa), streetcar operating costs per trip are higher than bus operating costs ($4.29 in Little Rock and $4.63 in Tampa, in 2010), whereas in the other cities the streetcar operating costs per trip are lower than the bus costs per trip.

Table 8. Operating Expense on U.S. Streetcars in Regular Revenue Service, 2010 (2011 dollars)

<table>
<thead>
<tr>
<th>City</th>
<th>Total</th>
<th>Per UPT</th>
<th>Per Pass. Mile</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2010</td>
<td>2010</td>
<td>2010</td>
</tr>
<tr>
<td>Little Rock</td>
<td>$1,024,033</td>
<td>$9.56</td>
<td>$6.18</td>
</tr>
<tr>
<td>Memphis</td>
<td>$4,208,069</td>
<td>$3.85</td>
<td>$4.58</td>
</tr>
<tr>
<td>New Orleans</td>
<td>$24,248,078</td>
<td>$4.09</td>
<td>$1.58</td>
</tr>
<tr>
<td>Portland</td>
<td>$5,500,000</td>
<td>$1.39</td>
<td>n/a</td>
</tr>
<tr>
<td>Seattle</td>
<td>$2,318,808</td>
<td>$4.45</td>
<td>$4.92</td>
</tr>
<tr>
<td>Tacoma</td>
<td>$3,150,604</td>
<td>$3.63</td>
<td>$3.62</td>
</tr>
<tr>
<td>Tampa</td>
<td>$2,583,860</td>
<td>$5.38</td>
<td>$3.27</td>
</tr>
</tbody>
</table>

Source: FTIS extraction from NTD (inflation adjusted 2011 dollars), www.ftis.org. Portland Data from Portland Streetcar, Inc.

The table reports operating expense on a per-passenger-mile basis for the six cities for which passenger mile data are available, with variability reflecting both differences in average trip lengths and differences in service costs. The per-passenger-mile costs for all the streetcar systems are significantly higher than their bus counterparts for the most recent available year (2010). While the streetcar operating costs per passenger mile range from $1.58 to $6.18 per passenger mile—a large range—bus operating costs per passenger mile in 2010 ranged from $0.78 per passenger mile (Memphis) to $1.65 per passenger mile (New Orleans), a much narrower range (Florida Department of Transportation 2012).
The final pair of tables show streetcar service operated by each agency within the total transit ridership and service accounted for on all of the agency’s fixed-route modes. Table 9 examines ridership, on both an unlinked-passenger-trip and a per-passenger-mile basis. The table shows that the streetcar in New Orleans functions as an integral part of the system, carrying more than 40 percent of passenger trips and more than 30 percent of passenger miles carried by the transit system as a whole. The other streetcar systems are much more modest contributors to overall ridership. Table 10 provides the same type of comparison, but instead reports the amount of service provided. New Orleans and Memphis stand out in the group of cities as cases where a significant amount of agency service is provided on the streetcar lines. A quick comparison of the two tables, looking specifically at passenger trips contrasted with revenue hours, shows that all of the streetcar systems, except that in Little Rock, account for a larger percentage of trips than they do of service hours, suggesting that the agencies are gaining some operational efficiency through the deployment of streetcar service, at least in terms of passenger carriage per unit of service.

Table 9. Streetcar Ridership as a Share of Total Agency Fixed-Route Ridership (2007–2011)

<table>
<thead>
<tr>
<th>City</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
</tr>
</thead>
<tbody>
<tr>
<td>Little Rock</td>
<td>5.6%</td>
<td>4.3%</td>
<td>4.9%</td>
<td>4.3%</td>
<td>3.7%</td>
</tr>
<tr>
<td>Memphis</td>
<td>9.4%</td>
<td>9.2%</td>
<td>10.2%</td>
<td>9.9%</td>
<td>11.4%</td>
</tr>
<tr>
<td>New Orleans</td>
<td>18.0%</td>
<td>41.8%</td>
<td>41.5%</td>
<td>43.4%</td>
<td>42.6%</td>
</tr>
<tr>
<td>Portland</td>
<td>3.4%</td>
<td>3.6%</td>
<td>3.7%</td>
<td>3.7%</td>
<td>3.5%</td>
</tr>
<tr>
<td>Seattle</td>
<td>n/a</td>
<td>0.3%</td>
<td>0.4%</td>
<td>0.5%</td>
<td>0.6%</td>
</tr>
<tr>
<td>Tacoma</td>
<td>6.7%</td>
<td>5.8%</td>
<td>4.7%</td>
<td>3.8%</td>
<td>3.9%</td>
</tr>
<tr>
<td>Tampa</td>
<td>4.5%</td>
<td>3.3%</td>
<td>3.8%</td>
<td>3.5%</td>
<td>2.6%</td>
</tr>
</tbody>
</table>

Source: FTA 2012. Note: Fixed Route includes all bus and rail modes, but excludes demand response and vanpool services.
Table 10. Streetcar Service as a Share of Total Agency Fixed-Route Service (2007–2011)

<table>
<thead>
<tr>
<th>City</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
</tr>
</thead>
<tbody>
<tr>
<td>Little Rock</td>
<td>1.9%</td>
<td>1.7%</td>
<td>1.6%</td>
<td>2.3%</td>
<td>1.8%</td>
</tr>
<tr>
<td>Memphis</td>
<td>6.4%</td>
<td>6.2%</td>
<td>5.6%</td>
<td>4.7%</td>
<td>4.8%</td>
</tr>
<tr>
<td>New Orleans</td>
<td>6.3%</td>
<td>19.8%</td>
<td>18.1%</td>
<td>20.2%</td>
<td>19.4%</td>
</tr>
<tr>
<td>Portland</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
<td>0.0%</td>
</tr>
<tr>
<td>Seattle</td>
<td>n/a</td>
<td>0.2%</td>
<td>0.2%</td>
<td>0.2%</td>
<td>0.2%</td>
</tr>
<tr>
<td>Tacoma</td>
<td>0.9%</td>
<td>0.8%</td>
<td>0.7%</td>
<td>0.6%</td>
<td>0.5%</td>
</tr>
<tr>
<td>Tampa</td>
<td>1.1%</td>
<td>1.1%</td>
<td>1.0%</td>
<td>0.9%</td>
<td>1.0%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>City</th>
<th>Vehicle Revenue Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Little Rock</td>
<td>5.9% 5.2% 5.1% 7.0% 5.6%</td>
</tr>
<tr>
<td>Memphis</td>
<td>13.3% 12.6% 12.0% 10.9% 9.8%</td>
</tr>
<tr>
<td>New Orleans</td>
<td>11.7% 27.6% 27.2% 29.7% 29.7%</td>
</tr>
<tr>
<td>Portland</td>
<td>1.8% 1.9% 1.8% 1.3% 1.3%</td>
</tr>
<tr>
<td>Seattle</td>
<td>n/a 0.4% 0.4% 0.4% 0.4%</td>
</tr>
<tr>
<td>Tacoma</td>
<td>1.9% 1.8% 1.5% 1.3% 1.3%</td>
</tr>
<tr>
<td>Tampa</td>
<td>2.9% 2.7% 2.4% 2.2% 2.4%</td>
</tr>
</tbody>
</table>

Source: FTA 2012. Note: Fixed-route includes all bus and rail modes, but excludes demand response and vanpool services.

Conclusion
This descriptive overview provided some basic insights into how streetcars are functioning and performing in terms of their role as public transportation modes in seven U.S. cities. There is significant variation in performance, with some of this variation a function of the built environment within which the systems operate and/or of the degree of integration with the rest of the transit system, captured in the transfer rates. In all of the cases, the streetcars are not operating faster than the agency’s typical motor buses in revenue service, although they are providing service that riders value, as reflected by the higher numbers of trips served per hour of service, particularly in Portland, Tacoma, Seattle, and New Orleans. This is not to say that in all of the four more successful cases the streetcars are necessarily better transit investments than regular buses, higher quality buses, or a different type of rail service. This analysis did not consider the capital expenses of these invest-
ments, which are significant and exceed those related to bus transit service. Future research is needed to address these significant questions.

The difficulty encountered in obtaining data on streetcar service from many of the agencies in this study suggests that many do not really view the streetcars as primarily transit service but instead view them more as development catalysts or as devices used to serve tourists and shoppers as opposed to regular transit riders. Whether this is an effective strategy or not is also something beyond the scope of this study, but it is indicative of a dilemma in these fiscally-constrained times, given that streetcar projects funded by the federal government’s resource-strapped capital grants program use resources that might have been used for other projects designed primarily to transport regular transit riders. Future research is clearly needed to consider these and other resource apportionment decisions in terms of their equity and effectiveness as alternative public transportation investment strategies. Streetcars might make sense to a local community as part of a tourist development or economic development strategy, but, if so defined, they should probably not be funded principally from transit funds. At a minimum, better data collection is needed to permit a more informed evaluation of the performance of these public transit investments. Promoters of these investments should also be clear about the relative importance of the transit and non-transportation roles these investments are designed to play.

**Acknowledgments**

The author wishes to thank the following individuals at the transit agencies examined in this paper for their invaluable assistance in providing agency data and documents: Carol Cooper, Rob Coughlin, Kay Dannen, Lynn Dupont, Steve Feigenbaum, Virginia Johnson, John Lancaster, Stefan Marks, Jason Sappington, and Betty Wineland.

**References**


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Examining the Ridership Attraction Potential of Bus Rapid Transit: A Quantitative Analysis of Image and Perception

Alasdair Cain, Research and Innovative Technology Administration, USDOT
Jennifer Flynn, National Bus Rapid Transit Institute (NBRTI)

Abstract

If public transit is to attract discretionary riders, it must offer high-quality service and convey an attractive image. Although Bus Rapid Transit (BRT) is designed to emulate rail-based transit, there is little quantitative evidence of whether BRT can capture the ridership attraction benefits associated with rail. A combination of focus groups and an attitudinal survey were conducted to assess BRT’s ability to replicate the high-quality image and ridership attraction benefits associated with rail, and to quantify the tangible and intangible factors that drive perceptual differences between alternative transit modes. Research was fielded in Los Angeles due to the city’s range of rapid transit modes. Overall, findings show that full-service BRT can replicate both the functionality standards and image qualities normally associated with rail, and that even a lower-investment “BRT-lite” service performs remarkably well in terms of overall rating achieved per dollar invested. More generally, results indicate that the image of the surrounding urban area may have greater influence on aggregate perceptions than whether a transit service is based on bus or rail technology.
Introduction

Bus Rapid Transit (BRT) is a term used to define a bus-based rapid transit service that attempts to emulate the high-quality service of rail-based transit modes, at a fraction of the capital cost. Initially pioneered in Latin America in the 1970s, BRT in the United States has been steadily gaining traction since the late 1990s and is a modal alternative in nearly every planning study today. Nonetheless, transportation professionals, local government officials, and politicians are still becoming acquainted with the concept and its potential applications. Viewed by BRT advocates as a cost-effective solution to urban mobility problems, the role of BRT is becoming increasingly associated with the wider objective of congestion reduction.

It is common knowledge within the transit industry that “image” is important to BRT. Sleek-looking vehicles, rail-like stations, advanced technologies, and a strong brand identity are just a few of the features that help communicate the message that “this is not just a regular bus service.” However, despite widespread recognition of its importance, little is actually known about this topic. Can BRT capture the high-quality image of rail systems, and if so, what is the most cost-effective way to accomplish this? How do different BRT design features contribute to overall image? How does image impact ridership attraction? These are some of the questions that led the Federal Transit Administration (FTA) to fund the National Bus Rapid Transit Institute (NBRTI) study, “Quantifying the Importance of Image and Perception to Bus Rapid Transit” (Cain et. al. 2009) (available at http://www.nbrti.org/research.html). This paper summarizes the study and presents its major findings.

Background

Tangible and Intangible Service Attributes

The creation of an image and identity separate from local on-street bus operations is an important objective of BRT. Research has shown that if transit is to attract discretionary riders, it must not only offer competitive travel times and high-quality service, but also be complemented by an attractive image. Unfortunately, bus-based public transit in the U.S. suffers from an image problem. Many people perceive the bus as an inferior way to travel, completely at odds with the mobility, convenience, and personal freedom afforded by the automobile. Some of the most common negative views regarding bus service are that it is unreliable, time-consuming, inaccessible, inconvenient, crowded, dirty, and unsafe (Wirthlin Worldwide and FCJandN 2000).
There is a general impression within the transit industry that rail service is inherently more attractive than bus service and is therefore a necessity for conveying the image of premium service. It has been argued that rail will attract more riders than conventional bus, even if all objectively quantifiable, or “tangible,” service attributes (e.g., travel cost, travel time, service frequency) are equal. This perceived advantage is attributed to qualitative and somewhat abstract, or “intangible,” factors (e.g., comfort, ride quality, safety) for which rail is thought to be superior. This premise—that difficult-to-measure, subjective factors underlie an innate preference for rail—is the basic rationale for employing bias constants in mode choice modeling. Given that standard models generally include only tangible factors, bias constants are introduced to capture the otherwise unmeasured impact of intangible factors (Ben-Akiva and Morikawa 2002).

As a rapid transit mode that is designed to emulate rail, BRT aims to capture at least some of the ridership attraction benefits associated with this high-investment mode. Although rail has an advantage over conventional bus service in terms of ridership attraction potential, there is little quantitative information on how BRT compares to rail in this regard. However, research by Ben-Akiva and Morikawa (2002) indicates that when quantifiable service characteristics are equal, riders may find high-quality bus alternatives equally attractive to rail transit for CBD-oriented commutes. Currie (2005) considers tangible and intangible factors in his argument that BRT and rail should generate equal ridership when the total trip attributes of both alternatives (travel time, cost, ride quality, transfers, and quality facilities) are equal. Henke (2007) draws on the findings of several different studies to conclude that up to one third of median ridership gain observed across six new BRT systems could not be explained by quantifiable service improvements, and that most of this unexplained aspect was due to brand identity.

Jointly, these studies lay the theoretical framework for the research presented in this paper: that service attributes (both tangible and intangible), rather than an innate preference for a particular mode or technology, explain the relative passenger attractiveness of rail and BRT. Thus, we hypothesized that for BRT to attract riders at a level similar to rail, it must be comparable to rail in terms of both tangible and intangible service attributes. To investigate this issue, we designed a study to (1) assess BRT’s ability to convey the high-quality image typically associated with rail-based transit and (2) examine and quantify the tangible and intangible factors that drive perceptual differences between alternative transit modes.
Defining BRT: From BRT-Lite to Full-Service BRT

When considering the image of BRT, it is important to note that the term BRT covers a wide spectrum of different applications. Although there are many different ways to subdivide these applications, BRT is often classified on the basis of running way type, which plays a central role in determining the investment cost and performance of the system.

The BRT mode is often viewed as bridging the gap between the local bus system and light rail transit; however, this gap is significant and covers a wide range of applications.1 At the lower end of the investment spectrum are the “BRT-lite” systems (also known as “rapid bus” or “low-level BRT”) that typically run in mixed traffic, using relatively low-cost applications such as traffic signal priority (TSP), intersection queue jumps, headway-based schedules, and far-side stops to improve commercial speeds and reliability. One of the best known and most successful examples of this approach is the Metro Rapid in Los Angeles.

BRT systems often feature some form of exclusive running way to guarantee high commercial speeds and reliability during peak periods. The most basic form is a shoulder bus lane, which can often be provided at minimal cost by simply restriping an existing lane or using a lane formerly designated for parking or loading and unloading. An added advantage of the bus lane approach is that it may be applied to specific route sections only or to operate during specific time periods, such as the morning and evening peaks.

Median bus lanes and median busways represent the next level up in terms of performance and investment. Locating the bus lane in the median tends to reduce the number of conflicts caused by side-street access, illegally parked cars, and other obstructions, thus providing higher performance levels. While typically more expensive than median bus lanes, median busways provide the added advantage of physically separating the running way from other traffic.

At the high end of BRT investment and performance are exclusive busways. Often described as “full-service” BRT or “high-level BRT,” these require obtaining the necessary right-of-way, which can often be achieved by using existing transit alignments such as abandoned rail lines. Although complete grade separation is nearly

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1 The authors recognize that the “conventional” view of BRT as simply a low-cost alternative to light rail transit (LRT) is an oversimplification. Recent research has shown that BRT and LRT are distinctly different modes, each with its own strengths and weaknesses. Indeed, it has been argued that BRT can match or even surpass the performance of LRT under certain circumstances. For more detailed information on this topic, please see Hoffman (2008).
impossible, exclusive busways are designed to minimize the number of at-grade intersections. Modern applications of this high-investment approach generally feature amenities more commonly associated with rail systems, including high-quality permanent stations, level boarding, off-board fare payment, and stylized vehicles (although these features are increasingly being provided at lower levels of investment as well). An example of this approach is the Metro Orange Line in Los Angeles.

On the matter of defining BRT, it should be noted that recent federal legislation under the Moving Ahead for Progress in the 21st Century Act (MAP-21) creates two fundamental classes of BRT projects: corridor-based and fixed-guideway. Both types of BRT must demonstrate substantial transit investment through features such as defined stations, TSP, short headways, and bidirectional service for a significant portion of weekday and weekend service. However, while fixed-guideway BRT must operate in a dedicated right-of-way during peak hours for the majority of the project length, there is no such provision for corridor-based BRT projects. Considering the wide spectrum of BRT applications discussed above, BRT-lite would typically equate with corridor-based BRT, while the exclusive running way applications, if constituting a majority of the project, would fall under fixed-guideway BRT.

**Study Methodology**

The study was designed to address the following core questions:

- Do people perceive alternative rapid transit modes differently?
- If differences exist, where do they originate?
- To what extent can differences in ridership attraction potential be attributed to individual tangible and intangible service attributes?
- What variations exist with regard to socio-economic/geographic factors?

The project was designed around two market research exercises: a series of focus groups, followed by an attitudinal survey. Los Angeles was chosen as the location for these exercises because it features many different rapid transit modes, including BRT-lite (Metro Rapid) and full-service BRT (Orange Line), as well as light rail transit (Blue and Gold Lines) and heavy rail transit (Red Line). Following is a description of the different transit modes in Los Angeles that were considered in this study. Table 1 provides summary statistics for each mode.
<table>
<thead>
<tr>
<th></th>
<th>Local Bus</th>
<th>Metro Rapid&lt;sup&gt;2&lt;/sup&gt; (BRT-lite)</th>
<th>Blue Line (LRT)</th>
<th>Orange Line (BRT)</th>
<th>Gold Line (LRT)</th>
<th>Red Line (HRT)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Av. weekday boardings</td>
<td>850,553</td>
<td>242,000</td>
<td>74,803</td>
<td>20,138</td>
<td>22,543</td>
<td>140,943</td>
</tr>
<tr>
<td>Annual boardings (FY2008)</td>
<td>308.35M</td>
<td>71.72M</td>
<td>24.56M</td>
<td>7.46M</td>
<td>6.58M</td>
<td>43.59M</td>
</tr>
<tr>
<td>System length (mi)</td>
<td>2,831&lt;sup&gt;1&lt;/sup&gt;</td>
<td>369</td>
<td>22</td>
<td>14</td>
<td>13.7</td>
<td>17.4</td>
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<tr>
<td>Capital cost</td>
<td>$206.2M&lt;sup&gt;4&lt;/sup&gt;</td>
<td>$123.3M</td>
<td>$87.7M</td>
<td>$330M</td>
<td>$859M</td>
<td>$4.5B</td>
</tr>
<tr>
<td>Capital cost/mi</td>
<td>$91,228</td>
<td>$354,798</td>
<td>$39.9M</td>
<td>$23.6M</td>
<td>$62.7M</td>
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<td>Capital cost (2005$)</td>
<td>$206.2M&lt;sup&gt;6&lt;/sup&gt;</td>
<td>$123.3M</td>
<td>$1,300M</td>
<td>$330M</td>
<td>$912M</td>
<td>$5.6B</td>
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<tr>
<td>Capital cost/mi (2005$)</td>
<td>$91,228</td>
<td>$354,798</td>
<td>$59.1M</td>
<td>$23.6M</td>
<td>$66.6M</td>
<td>$321.8M</td>
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<tr>
<td># of stops/stations</td>
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<td>543</td>
<td>22</td>
<td>14</td>
<td>13</td>
<td>16</td>
</tr>
<tr>
<td># of rail cars/buses in fleet</td>
<td>2,261&lt;sup&gt;6&lt;/sup&gt;</td>
<td>452</td>
<td>69</td>
<td>30</td>
<td>24</td>
<td>104</td>
</tr>
<tr>
<td>Peak headway (mins)</td>
<td>varied</td>
<td>2.5–10</td>
<td>5–7</td>
<td>4–5</td>
<td>10</td>
<td>4–6</td>
</tr>
<tr>
<td>Off-peak headway (mins)</td>
<td>varied</td>
<td>10–20</td>
<td>12–20</td>
<td>10–20</td>
<td>12–20</td>
<td>6–19</td>
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<tr>
<td>Weekday service span (hrs)</td>
<td>varied</td>
<td>15</td>
<td>22.1</td>
<td>21.8</td>
<td>21.3</td>
<td>20.9</td>
</tr>
<tr>
<td>Service area</td>
<td>City-wide network</td>
<td>City-wide network</td>
<td>South L.A., Watts, Compton, L. Beach</td>
<td>South San Fernando Valley</td>
<td>Highland Park, South Pasadena</td>
<td>Downtown L.A., Hollywood, N. Hollywood</td>
</tr>
</tbody>
</table>

<sup>1</sup> Statistics current as of 2009, courtesy of LACMTA staff and website www.metro.net.

<sup>2</sup> Metro Rapid data are for 25 lines operated by LACMTA only.

<sup>3</sup> From FY08 National Transit Database (NTD) Motor Bus (MB) Directly Operated (DO) Directional Route miles from S-10 Report. The Local Bus data are annual NTD number minus Metro Rapid Bus stated amount in matrix.

<sup>4</sup> Total annual capital project cost from LACMTA FY09 Budget Book for projects in following categories: Bus Acquisition, Bus Facility Improvements, Bus Maintenance, and ITS (3 projects – TOAST, ATMS and TAP Clearinghouse).

<sup>5</sup> The local bus and Metro Rapid capital costs are an aggregation of costs accrued incrementally over time. Thus, they have not been adjusted to 2005 dollars.

**Metro Local**

Metro Local is the conventional bus service that operates throughout the city. Buses are distinguished by their bright orange color, although a number of older buses remain white with an orange stripe.

**Metro Rapid (BRT-Lite)**

The Metro Rapid is a well-known example of the lower-investment approach to BRT that operates in mixed traffic, known as BRT-lite or Rapid Bus. Delays are minimized through the use of headway-based schedules, higher-frequency service, a simplified route design, more widely-spaced stops, and signal priority measures. Other elements include low-floor buses, a unified brand identity, and enhanced stops with amenities such as lighting, canopies, and real-time information. Growing steadily since two initial pilot corridors were opened in 2000, the Metro Rapid now consists of a 450-mile network of routes throughout the city (see Figure 1). While the Metro Rapid service is provided primarily by standard 40 ft vehicles, some 60 ft articulated vehicles are now used on the highest-demand routes.

**Orange Line (Full-Service BRT)**

The Metro Orange Line opened in 2005 as one of the first full-service BRT systems in the United States. At the time of this study, it comprised a 14-mile dedicated busway running east-west through the San Fernando Valley and connecting to the Red Line at its eastern terminus in North Hollywood. In June 2012, the busway was extended four miles northward from Canoga Station to the Chatsworth Metro Link commuter rail station. The Orange Line features 60 ft articulated vehicles, permanent stations, level boarding, off-board fare payment, and headway-based schedules. Vehicles are powered by compressed natural gas (CNG) and feature aerodynamic styling, panoramic windows, low floors, wide aisles, and three extra-wide doors. Stations offer various amenities, including bicycle racks and lockers, covered seating, ticket vending machines, telephones, and enhanced lighting. To give the Orange Line a premium service image, Metro has branded the route as part of the city’s rapid transit network (see Figure 2).
Figure 1. Los Angeles Metro rail system map
Source: Los Angeles County Metropolitan Transportation Authority, www.metro.net

Figure 2. Metro Rapid network map
Blue Line (Light Rail)
The first and longest of MTA’s modern light rail lines, the Metro Blue Line runs north-south for 22 miles between downtown Los Angeles and downtown Long Beach. Opened in 1990, the line serves 22 stations and traverses much of the densely-populated area through South Los Angeles, Watts, Willowbrook, Compton, and Long Beach, which includes some of the most economically-deprived areas of the city.

Gold Line (Light Rail)
The Metro Gold Line opened in 2003. At the time of this study, it spanned 13.7 miles from eastern Pasadena to downtown Los Angeles, along a disused railroad right-of-way adjacent to the heavily-congested Pasadena and Foothill freeways. The service has since been extended six miles eastward from its original terminus at Union Station in downtown to Atlantic Station in East Los Angeles, bringing the total line length to 19.7 miles.

Red Line (Heavy Rail)
The Metro Red Line, the highest ridership rail line in Los Angeles, operates solely underground and spans 17.4-miles, providing high-speed service to the city’s most densely-populated areas. Service runs from downtown Los Angeles to North Hollywood via the jewelry, retail, and financial districts and the neighborhoods of Westlake and Hollywood. The eastern terminus at downtown’s Union Station provides connections to AmTrak, Metro Local, Metro Rapid, and the Metro Gold Line; the Metro Blue Line can be accessed at 7th St/Metro Center; transfers to the Metro Orange Line BRT can be made at the end of the line in North Hollywood.

Focus Groups
Objectives
The focus group exercise was designed to address the following objectives:

- Explore public attitudes toward the different rapid transit modes and the private auto
- Gain an understanding of the influence of urban context and socio-economic factors on public perceptions of different rapid transit modes and the private auto
- Identify the tangible and intangible factors that influence mode choice decisions
Methodology
The sampling methodology was designed to focus on people with viable modal alternatives for their everyday travel needs, making use of a transit market segmentation concept developed by Krizek and El-Geneidy (2007). Four market segments were defined. People using transit were divided into “choice users” (people with access to a private vehicle) and “captive users” (people without other means of transportation). People not using transit were divided into “potential users” (people that could use transit but choose not to) and “auto users” (people without a transit option for their trips, also known as “auto captive”).

A local market research firm was hired to perform sample recruitment and provide a venue for the focus groups, which were conducted in the Universal City area of Los Angeles in November 2007. The authors were responsible for group moderation and qualitative data analysis. Group sampling criteria were designed to ensure diversity in terms of age, income, ethnicity, and gender. Most of the participants were choice users of one or more of the different rapid transit modes, although a smaller sample of potential users also was recruited. Thus, all focus group participants had access to a private vehicle. This was to ensure that the people recruited for the focus groups had some level of mode choice available to them in their daily travel behavior. Sample quotas were defined to ensure representative choice users of each of the following modes: local bus, Metro Rapid (BRT-lite), Orange Line (full-service BRT), Gold/Blue Line (LRT), and Red Line (HRT), as well as representatives of the potential user group. People who were captive, either to transit or the automobile, were screened out of the study.

Identification of Tangible and Intangible Service Attributes
Qualitative analysis of the focus group transcripts provided a rich source of information on perceptions of life and travel in the Los Angeles metropolitan area and detailed views on each of the travel modes included in the study. For more information on these issues, please refer to the final project report document. The focus group information also allowed the authors to identify a large number of service attributes affecting overall modal perceptions. Most of the tangible factors were previously identified in the literature as standard inputs of transit travel demand and mode choice models, although reliability was identified in some literature sources as one of the intangible factors typically captured by mode bias constants.

It was found that each focus group participant typically mentioned a range of both tangible and intangible factors when comparing the different modes with each other and with private vehicle use. Regular transit users tended to be more
focused on the tangible attributes such as service span, frequency, and cost, while less frequent users were more likely to cite intangible attributes (service is unsafe, buses are overcrowded or uncomfortable).

Following the factor identification process, factors were separated into tangible and intangible variable groups and then synthesized into 14 core variables for further analysis in the attitudinal survey. These variables, as presented in the survey, are described in Table 2.

**Attitudinal Survey**

The survey exercise was designed to quantify the relative importance of the different tangible and intangible factors identified in the focus groups and to determine the contribution of each to the overall ridership attraction potential of the different rapid transit modes. A local Los Angeles market research firm was hired to work with the study authors in the development of the survey methodology and survey instrument, to conduct the survey, and to analyze the survey data. The survey was fielded in the fall of 2008.

<table>
<thead>
<tr>
<th>Tangible Factors</th>
<th>Intangible Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Travel Cost</strong> – transit fares, plus related costs like parking</td>
<td><strong>Safety while riding the service</strong> – safety from accidents and/or crime</td>
</tr>
<tr>
<td><strong>Door to door travel time</strong></td>
<td><strong>Comfort while riding</strong> – seats available, temperature, smooth ride, cleanliness, etc.</td>
</tr>
<tr>
<td><strong>Frequency of Service</strong> – how often the service runs</td>
<td><strong>Safety at the station/stop</strong> – safety from accidents and/or crime</td>
</tr>
<tr>
<td><strong>Hours of service</strong> – how early or late service runs, and/or weekend hours</td>
<td><strong>Comfort at the station/stop</strong> – shelter from weather, amenities, etc.</td>
</tr>
<tr>
<td><strong>Convenience of service</strong> – goes where you need to go/parking availability</td>
<td><strong>Customer service</strong> – provided by drivers and other transit service staff</td>
</tr>
<tr>
<td><strong>Reliability of service</strong> – does the service run on time?</td>
<td><strong>Ease of service use</strong> – clear service info, routes easy to figure out, etc.</td>
</tr>
<tr>
<td><strong>Avoid stress/cost of car use</strong> – traffic, parking, accidents, tickets, etc.</td>
<td><strong>Other riders</strong> – feeling secure/at ease/compatible with others using service</td>
</tr>
</tbody>
</table>

**Survey Methodology**

A sampling methodology was developed to yield valid and reliable demographic profiles that could be generalized to the universe of riders of each transit mode.
and for non-riders (± 5% accuracy at the 95% confidence level). Two corridors were selected that have access to a majority of the different modes being rated. The San Gabriel Valley Corridor offered parallel light rail, express bus (Gold Line/BRT-lite), and local bus service. The San Fernando Valley Corridor offered parallel high-level BRT service (Orange Line), express bus, and local service. In addition, both corridors connect to the central business district and to the Red Line, which is the heavy-rail mode evaluated in this study.

A total sample of 2,390 respondents was obtained, including approximately 400 respondents for each of the 6 identified transit modes, obtained through on-board surveys (with telephone call-back for incomplete surveys) and a Random-Digit-Dialing telephone survey of approximately 400 non-transit users. Respondents were categorized into the four market segments identified by Krizek and El-Geneidy (2007). Approximately two-thirds (66%) of transit users were identified as transit captive, whereas non-users were nearly evenly split into auto captive (47.9%) and potential users (52.1%).

While the study’s ultimate goal was to assess how perceptions of the different travel modes were linked to ridership attraction potential, it was recognized that it would be difficult to do this directly, due to the geographically dispersed nature of the study modes (for example, respondents residing in south or west Los Angeles would be unlikely to ever ride the Gold Line, no matter how positive their perceptions of this service). To overcome this, the overall rating assigned by respondents to each mode (ranging from “very poor” to “very good”) was used as a proxy for ridership attraction potential, as it was assumed that respondents would be able to provide a general opinion of any service they were asked about, provided they were aware of it, even if they were not in a position to use it. Those unaware of any particular service were not asked for their opinion of it.

**Study Findings**

Statistically significant differences were observed in the mean overall ratings achieved by each of the alternative transit modes, which were separated into four distinct tiers. These four tiers are shown below, ordered from lowest to highest in terms of average overall rating achieved:
- Tier 1: Local bus service (mean overall rating of 3.70)
- Tier 2: Metro Rapid BRT and Blue Line LRT (mean overall ratings of 4.01 and 3.98, respectively)
- Tier 3: Orange Line BRT and Gold Line LRT (mean overall ratings of 4.08 and 4.06, respectively)
- Tier 4: Red Line HRT (mean overall rating of 4.18)

It was noted that level of investment appeared to be an influencing factor, with the lowest and highest investment modes (the local bus and the Red Line HRT) achieving the lowest and highest mean ratings respectively. Thus, the mean overall ratings were compared against the actual level of investment associated with each mode, defined as capital cost per mile in 2005 dollars.²

![Figure 3. Overall rating of each transit mode versus capital cost per mile](image)

² It recognized that capital costs are only one aspect of the overall cost of a transit investment, and that a more accurate comparison of the cost effectiveness of different types of transit investment would consider “lifecycle cost,” which includes capital costs plus operational costs summed over the lifetime of the system. Capital costs have been used here due to difficulties experienced in finding comparable operational cost data for each of the modes under consideration.
This analysis revealed a large disparity in investment level, with the Red Line costing approximately 1,000 times more per mile than the local bus service and Metro Rapid. For the Tier 2 services, it was observed that the Metro Rapid achieved a slightly higher rating than the Blue Line (although statistically, these two are considered to have the same rating), for a fraction of the investment cost ($0.355M per mile versus $59.1M per mile). Given that the investment level of the Metro Rapid is much closer to that of the local bus than to any of the other modes, it must be concluded that the Metro Rapid performed remarkably well in terms of overall rating achieved per dollar of investment, and thus represents a very cost-effective form of BRT.

Considering the Tier 3 services, it was observed that the Orange Line achieved a slightly higher rating than the Gold Line (though again, in statistical terms these two are rated the same) for approximately one-third of the investment cost. This indicated that the Orange Line also performs well in overall rating per dollar of investment, although not to the dramatic level of the Metro Rapid. Overall, these findings showed that BRT, even in its lower-investment form, can compete with rail-based transit (at least in the perception of the general public) in return for lower capital cost investments.

Aside from the two obvious extremes of the local bus and the Red Line, the ratings achieved by the remaining transit services were not simply proportional to respective levels of investment; clearly, other variables were involved. First, why were the Blue and Gold Lines rated differently, even though they are the same mode, at approximately the same level of investment? Further investigation showed that the higher overall rating achieved by the Gold Line was attributed primarily to higher ratings for key intangible variables: safety (both at the station and onboard) and perceptions of other riders. Interestingly, these same intangible variables were also chiefly responsible for the Orange Line achieving a higher overall rating than the Blue Line. The focus group work suggested that these results speak to the wider issue of urban context. The Blue Line runs through some of the most economically-deprived areas of the city, while the Gold and Orange lines serve relatively affluent areas; thus, it appears that these differences in urban context are largely responsible for the discrepancy in overall rating between these modes. Furthermore, it appears that urban context is more influential in determining overall perceptions than whether the service is rail- or bus-based. Since the Orange Line achieved similar ratings to the Gold Line for both tangible and intangible attributes, the authors concluded that full-service BRT is capable of replicating both the functionality
standards and image qualities normally associated with LRT, at least in the perception of the general public. In the words of one focus group participant, “It’s not a bus, it’s a train-bus.”

It was also important to understand how the two different forms of BRT, representing opposite ends of the BRT investment spectrum, are viewed by the public. It was found that the Orange Line’s significantly higher overall rating originated in higher ratings on both the tangible and intangible attributes, although by far the largest single difference was in relation to station comfort. That the Orange Line received superior ratings for both tangible and intangible attributes implies a greater likelihood of success in attracting the coveted “potential rider” market (those that could ride transit but choose to travel by private auto instead). However, while the Orange Line is perceived as superior, it should be noted that the Metro Rapid achieved an overall rating that was only slightly lower, while costing around 100 times less per mile to provide.

Finally, it was important to understand why the Metro Rapid BRT-lite system achieved significantly higher ratings than the local bus system, although both run in mixed traffic. The most significant differences were found in relation to travel time, followed by frequency and reliability. So whereas the Metro Rapid also achieved higher ratings on important intangible attributes like safety and comfort, it appears that the attraction of BRT-lite over local bus relates to higher perceived levels of functional service performance.

Some progress was made in understanding the influence of different tangible and intangible factors on overall perceptions of each mode. Figure 4 illustrates the average importance rating assigned to each tangible and intangible factor. In terms of importance, the tangible attributes of reliability and service frequency received the highest ratings, along with the intangible attribute of ride safety. These were closely followed by the tangible attribute of service span and the intangible attribute of station safety. Overall, it is clear that the public considers both tangible and intangible factors in determining their overall opinion of alternative transit services.
Although several different model formulations were tested, the index regression model was found to provide the most consistent explanatory power in linking individual service attributes (independent variables) to the mean overall ratings achieved by each mode (dependent variable). The model showed that local bus ratings were more heavily influenced by the tangible attribute group that included travel time, service span, and service frequency, while the rail modes were impacted more by the intangible safety/comfort factor group. Further research could test the hypothesis that functionality is more influential in the attractiveness of lower-investment bus-based services, which tend to focus on “no-frills” provision of basic mobility, while intangible aspects like safety and comfort are more influential in the attractiveness of higher-investment BRT and rail-based modes. It is conceivable that once basic mobility needs have been met, riders turn their attention to intangible aspects like safety and comfort. Such behavior would be consistent with Maslow’s well-known Hierarchy of Needs theory (1943), in which basic human physiological needs must be met before higher-level needs can be considered. Perhaps the same is true of mobility.
Conclusions

With regard to the four core questions posed at the study's inception, the following conclusions are provided:

1. **Do people perceive alternative rapid transit modes differently?** This study found that the general public does perceive alternative rapid transit modes differently, with the modes being separated into four distinct statistically different tiers in terms of mean overall rating achieved. Furthermore, BRT achieved overall ratings that were equivalent to light rail transit, and thus appears to be capable of capturing the image qualities normally associated with this higher-investment mode. The study also suggests that BRT, particularly a BRT-lite service like the Metro Rapid, offers a highly cost-effective form of transit investment.

2. **If differences exist, where do they originate?** As expected, the study showed that the level of investment associated with each mode clearly plays a role. Less expected was the indication that urban context may also have a significant influence, by directly impacting intangible service attributes like perceptions of safety. Indeed, it appears that the image of the urban area through which a transit service runs may be more important in determining aggregate perceptions than whether the service is rail- or bus-based. Thus, improving the image (most importantly, perceptions of safety) of the surrounding urban area may also improve the ridership attraction potential of a transit service.

3. **To what extent can differences in ridership attraction potential be attributed to individual tangible and intangible service attributes?** In addition to level of investment and urban context, a range of other factors clearly play a role in determining the ridership attraction potential (or, in this case, mean overall rating) achieved by each mode. This study found that public perceptions are driven by combinations of a wide range of different tangible and intangible service attributes, including tangible attributes like reliability, service frequency and span, along with intangible attributes like safety and comfort.

4. **What variations exist with regard to socio-economic/geographic factors?** The study found that the overall ratings for each transit mode, and the level of importance attributed to each tangible and intangible factor, were generally unaffected by the range of typical socio-economic/demographic variables such as gender, age, and income. The importance of the different tangible and
intangible attributes were cross tabulated across the various demographic variables and, due to the large sample size, most of them produced statistically significant differences, although they did not provide any actionable insights. Cost was rated more important by transit captives than by the other three market segments, and this difference was statistically significant. For transit choice riders, travel time was rated higher than for the other groups, and this difference was also statistically significant. It is not remarkable that cost would be more of an issue for transit captives, who tend to have lower-incomes, while travel time would be more of an issue for transit choice riders, who have the option of traveling by private auto.

In conclusion, it should be noted that Los Angeles was chosen as the location for this study because it features many different rapid transit modes in fairly close proximity, including full-service BRT, BRT-lite, light rail, and heavy rail. However, Los Angeles is a vast, auto-centric metropolitan area with some of the worst levels of traffic congestion in the country and, therefore, cannot be assumed to represent a typical North American city. Also, it must be noted that this study used mean overall ratings as a proxy for ridership attraction potential. Further research is required to verify whether this is a reasonable assumption and whether the study findings can be generalized to other urban areas. Future research work could expand upon this study's findings by focusing more on the important “potential user” group.

**Acknowledgments**

This research work was undertaken and completed while a co-author was a Senior Research Associate at CUTR/NBRTI/USF. The opinions, findings and conclusions expressed in this publication are those of the authors and do not necessarily reflect the views, positions or policies of the Research and Innovative Technology Administration or the U.S. Department of Transportation.

**References**


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Bike-and-Ride:
Build It and They Will Come

Robert Cervero, Benjamin Caldwell, Jesus Cuellar
University of California, Berkeley

Abstract

Converting park-and-ride to bike-and-ride trips could yield important environmental, energy conservation, and public-health benefits. While cycling in general is becoming increasingly popular in the United States, it still makes up a miniscule portion of access trips to most rail transit stations. At several rail stations of the Bay Area Rapid Transit (BART) system, 10 percent or more of access trips are by bicycle, up considerably from a decade earlier. This paper adopts a case-study approach to probe factors that have had a hand in not only cycling grabbing a larger market share of access trips to rail stops, but also in the enlargement of bike access-sheds over time. Both on-site factors, such as increases in the number of secure and protected bicycle parking racks, as well as off-site factors, such as increases in the lineal miles of separated bike-paths and bike boulevards, appear to explain growing use of bicycles for accessing rail stations. The adage “build it and they will come,” we argue, holds for bicycle improvements every bit as much as other forms of urban transportation infrastructure. Pro-active partnerships between transit agencies, local municipalities, and bicycle advocacy organizations are critical to ensuring such improvements are made.

The Case for Bike-and-Ride

Bicycling is becoming increasingly popular as a way to move about American cities. Between 1977 and 2009, the total number of bike trips in the U.S. more than tripled while cycling’s share of all trips nearly doubled (Pucher et al. 2011). The cycling
renaissance is most prevalent in several dozen U.S. cities that have invested heavily in cycling infrastructure, such as Portland, Oregon, and San Francisco, where the bike’s mode shares of all trips were 5.8 percent and 3.0 percent, respectively in 2009 (Pucher et al. 2011).

As a means of reaching America’s rail transit stations, cycling’s role remains miniscule, however. With the exception of a handful of regional rail systems, bicycles account for a fraction of one percent of all home-based access trips to most U.S. rail stops (Cervero 1995; Cervero 2003; Pucher and Buehler 2009). This is in stark contrast to countries such as Denmark and the Netherlands, where a quarter or more of all access trips to regional rail stops are by bicycle (Rietveld 2000; Martens 2004, 2007; Pucher and Buehler 2008). Shares are the highest in medium-size Dutch and Danish cities, where bikes account for 35 percent or more of access trips to rail stops (Martens 2007). In bigger cities such as Copenhagen and Amsterdam, the best habitat for bike-and-ride are suburban stations, which account for a third or more of rail access trips, even on rainy days (Cervero 2003; Martens 2004). In the U.S., walking is often preferred to cycling for reaching downtown and inner-city rail stations due to factors such as short access distances, higher risks of cycling accidents on busy streets, and limited bike parking possibilities at stations (Cervero 1995; Cervero 2003; Pucher and Buehler 2008). In suburban areas where travel distances for accessing stations tend to be longer, cycling’s mobility role might be expected to increase, as in Europe; however, this has generally not been the case, partly due to the prevalence of free station-area parking coupled with the dearth of bikeways and other cycling infrastructure.

Although cycling’s market share of rail access trips in the U.S. is paltry by European standards, numbers are trending upwards. Bike trips to and from bus and rail stops rose from one percent in 2001 to three percent in 2009 (Pucher et al. 2011). This upswing reflects, in good part, the complementary nature of cycling and public transit. Bicycling supports transit by extending the catchment areas of transit stops beyond a walking range, at a much lower cost than neighborhood feeder buses and park-and-ride facilities (Pucher and Buehler 2010). Upon exiting a station, bike-sharing facilities help solve the “last mile” problem. For cyclists, public transit can provide long-distance carriage and safe passage through highly-congested corridors.

What benefits would accrue for increasing cycling’s role as an access mode to transit stations? For one, “active transport” modes such as cycling provide obvious personal health benefits from increased physical activity. Having more riders engage in physical activity as part of the transit trip would be a positive step toward revers-
Bike-and-Ride: Build It and They Will Come

ing the obesity epidemic currently plaguing America (Pucher and Buehler 2010; Pucher et al. 2010). Environmental benefits would also result from converting park-and-ride trips to be bike-and-ride. Energy conservation and air-quality benefits go beyond less vehicle miles traveled (VMT). From an air quality standpoint, transit riding does little good if most people use cars to reach stations. For a three-mile automobile trip—the typical distance driven to access a suburban park-and-ride lot in the U.S.—the vast majority of hydrocarbon and nitrogen oxide emissions (the two main precursors to smog formation) are due to cold starts and hot evaporative soaks (Cervero 1995; Cervero 2001). Reliance on cars for accessing regional rail services significantly offsets the air-quality benefits of patronizing transit. Shifts from park-and-ride to bike-and-ride can also shrink surface parking lots and, thus, the amount of impervious asphalt surrounding stations. This, in turn, can reduce heat-island effects and oil-stained run-off into nearby streams, replenish local water aquifers, and bring nearby development closer to transit stops, thus creating more pedestrian-friendly surroundings. Last, investing in bike-and-ride facilities promotes social justice since many transit users have no or limited car access.

This paper investigates factors that have contributed to increased bike-and-ride activities for one particular U.S. transit agency: the San Francisco Bay Area Rapid Transit system, or BART. BART represents a best-case example, in the U.S., at least, due to proactive steps taken to increase the bicycle’s role in accessing rail stations. By one account, the “San Francisco Bay Area … has been at the vanguard of innovations to promote bike-and-ride” (Pucher and Buehler 2009, 96). Today, BART provides bike parking at almost all of its 43 stations, totaling more than 4,500 bike parking spaces and more than 1,000 secure bike lockers. Three of the 10 bike stations (that provide secure storage, short-term rentals, and on-site repairs) that existed at U.S. rail stations in 2009 were at BART stations (Pucher and Buehler 2009). Since 1990, BART’s share of public transit trips combined with cycling has more than tripled due to such factors.

Taking advantage of survey data compiled by BART on bicycle access to rail stations for two time points, the analysis begins by identifying particular types of BART stations that have experienced the largest percentage increases in bike-and-ride modal shares. Several stations that achieved the largest gains are then examined in more detail to illuminate factors that likely account for these trends. Due to limited numbers of data points, the focus here is less on establishing statistical correlations and more on uncovering patterns revealed by case experiences. In addition to studying modal shares, changes in bike access-sheds are mapped and
measured over two time points for several stations. The paper closes with discussions on policy and investment strategies for increasing the bicycle’s mobility role for accessing rail stations throughout the U.S.

Bikes and BART
BART recently celebrated its 40th anniversary, making it the oldest post-WWII metropolitan rail system in the United States. With nearly 400,000 weekday trips made on a 104-mile network, BART ranked as America’s fifth most patronized and third most extensive metropolitan rail network in 2012. Early on, BART was criticized for being a commuter-rail-like service masquerading as a metrorail system, owing to its long station spacings and plentiful park-and-ride provisions outside of San Francisco (Webber 1976). Vast expanses of surface parking around most of BART’s suburban rail stations has also been blamed for suppressing BART’s ability to spawn compact, mixed-use transit-oriented development (TOD), as envisioned when the system was first planned (Cervero and Landis 1997; Bernick and Cervero 1997). Today, surface parking remains the dominant land use immediate to the vast majority of the East Bay’s suburban BART stations.

It is against this backdrop that, over the past two decades, BART planners have sought to ratchet up the mobility role of bicycles for accessing stations. This has occurred not only by providing on-site bicycle parking spaces, secure lockers, and repair facilities, but also supporting the efforts of surrounding communities to provide off-site bike-paths and bike-lanes that feed into rail stops. Also important have been auto-restraint counter-measures, introduced on-site by BART (e.g., parking charges) and off-site by local communities (e.g., traffic calming).

Collectively, these measures appear to have paid off. Between 1998 and 2008, the number of bicycle trips made to BART stations grew by 69 percent, to more than 4 percent of all access trips. This is the highest share of access trips to rail stops of any U.S. metropolitan rail system, surpassing the agency’s three percent target of all access trips via bicycle set for 2010. By comparison, Washington Metrorail, a similar-size regional rail system that has also aggressively invested in bicycle infrastructure on- and near-site, averages less than 1 percent of all access trips by bicycle (Parsons Brinckerhoff 2010). Among large rail-served regions of the U.S., BART is coming as close to emulating some of Europe’s bike-and-ride successes as anywhere.
Trends by Station Type

Does the bicycle’s role as an access mode vary by type of BART station? Have access roles changed over time by station types? To address these questions, data on bicycle modal shares of all home-based access trips in 1998 and 2008 were stratified by five types of BART stations. Figure 1 shows five types of stations identified by BART, defined in terms of urban setting (e.g., levels of density), parking provisions, and automobile orientation. The five station types (and number of BART stations for each type) are: Urban (9 stations); Urban with Parking (6 stations); Balanced Intermodal (10 stations); Intermodal-Auto Reliant (6 stations); and Auto-Dependent (12 stations). BART’s Urban stations are situated in or near downtown San Francisco, Oakland, or Berkeley in dense, mixed-use settings with no parking. Urban with Parking stations lie in largely built-up neighborhoods that ring the downtowns of the same three cities and offer some off-street parking to customers. Balanced Intermodal stations are in mature suburban communities of the East Bay, with some parking and extensive feeder bus services. Intermodal-Auto Reliant stations are in largely low-density residential settings with extensive parking (thus, the “auto-reliant” title) but also with significant feeder bus connections. Auto-Dependent stations serve low-density bedroom communities in the suburbs of the East Bay where the private car reigns supreme, including for rail-station access.

Table 1 presents 1998 and 2008 statistical averages (and standard deviations) for bicycle access modal shares among BART stations, partitioned by each station type. Percentage point changes between the two time points are also presented (for stations that existed in both years). The table reveals significant differences in the bicycle access modal shares among the five types of BART stations for each time point as well as between the time points. A simple one-way ANOVA comparison of variations in modal shares between versus within station types shows significant differences (based on F statistics) for all three columns of data. In addition, the table shows that “Urban with Parking” stations—largely in fairly dense urban districts outside of downtown San Francisco, Oakland, and Berkeley, but with parking possibilities—averaged the highest bicycle access modal shares in 1998 and 2008. Moreover, these stations increased their margin of bike-access modal shares over time relative to the other four station types. Two other station types—“Urban” and “Intermodal-Auto Reliant”—also recorded respectable increases in the bicycle’s station-access modal shares. In 2008, “Auto-Dependent” stations—mostly surrounded by low-density suburban residences and large surface parking lots—were the least attractive among station types for accessing BART by bicycle.
Figure 1. Typology of BART station

Table 1. Summary of BART Station Access Modal Shares by Bicycle, in Percentages, Among Five Station Types: 1998, 2008, and Changes between 1998 and 2008

<table>
<thead>
<tr>
<th>Type of Station</th>
<th>No. Stations</th>
<th>Statistical Means (Std. Dev.)</th>
<th>1998</th>
<th>2008</th>
<th>% Point ∆ 1998-2008</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urban</td>
<td>9</td>
<td></td>
<td>3.42%</td>
<td>5.07%</td>
<td>1.65% (1.82%)</td>
</tr>
<tr>
<td>Urban with Parking</td>
<td>6</td>
<td></td>
<td>4.14%</td>
<td>7.03%</td>
<td>2.89% (1.93%)</td>
</tr>
<tr>
<td>Balanced Intermodal</td>
<td>10</td>
<td></td>
<td>2.67%</td>
<td>3.09%</td>
<td>0.42% (1.90%)</td>
</tr>
<tr>
<td>Intermodal-Auto Reliant</td>
<td>5</td>
<td></td>
<td>0.78%</td>
<td>2.24%</td>
<td>1.46% (1.56%)</td>
</tr>
<tr>
<td>Auto-Dependent</td>
<td>9*</td>
<td></td>
<td>1.53%</td>
<td>1.67%</td>
<td>0.29% (0.83%)</td>
</tr>
<tr>
<td>All Stations</td>
<td>39*</td>
<td></td>
<td>2.57%</td>
<td>3.62%</td>
<td>1.19% (1.82%)</td>
</tr>
<tr>
<td>One-way ANOVA</td>
<td>39*</td>
<td></td>
<td>4.93</td>
<td>5.48</td>
<td>3.01 (.031)</td>
</tr>
</tbody>
</table>

* Two Auto-Dependent BART stations (South San Francisco and San Bruno) did not exist in 1998 and thus are not included in the statistics for 1998 or change between 1998 and 2008 (but are included in the 2008 statistics, increasing the number of Auto-Dependent stations to 11 for that year). Also, two other BART stations (San Francisco International Airport and Millbrae) did not exist in 1998 either and thus are likewise excluded from the analysis, including for 2008, because of the absence of bicycle access options to these stations.

Source: Databases on ridership surveys compiled in 1998 and 2008 were obtained from BART planning department.

Mean statistics in Table 1 varied to a considerable degree among stations within each grouping, as revealed by standard deviations. Notably, there was fairly high variation in changes in the bicycle’s modal shares between 1998 and 2008 within station groups. This indicates that a handful of stations stood out for their high levels of station-access by bike relative to other stations within the same group. Most notable are two stations in the highest scoring station type, “Urban with Parking”: Ashby Station in Berkeley and Fruitvale Station in Oakland. The Ashby station, situated on the Richmond line in a transition zone between north Oakland and Berkeley (see Figure 1), averaged the highest bike shares in both 1998 (7.39%) and 2008 (11.75%), and also had the second-highest percentage point increase in cycling...
access (4.36) over the two time points. The station with the highest percentage point change between 1998 and 2008 was Fruitvale (5.62). The Fruitvale Station, situated on the Fremont BART line south of downtown Oakland (see Figure 1), went from the eight-highest bike-access modal share in 1998 (4.30%) to the second-highest in 2008 (9.92%, second only to the Ashby station).

Clearly, some significant changes happened at these two stations over this 10-year period that made them considerably more attractive to cyclists for accessing BART. What were these? The remainder of this paper examines this question by investigating changes in on- and off-station cycling infrastructure and other policies at and around both stations over this period. In addition to associating changes to bike-access modal shares, bike-access travel-sheds are measured and mapped out in 1998 and 2008 to provide a spatial perspective to the research. Last, these two “best case” experiences are contrasted to those of the Balboa Park station in San Francisco, which was the “Urban with Parking” station that had the lowest bike-access modal share in 2008 (1.86%) and recorded a fairly small increase over the 1998–2008 period (1.17 percentage points) relative to other stations in this group.

**Bicycle Access to Ashby BART Station**

With well over 10 percent of access trips by bicycle, the Ashby BART station is one of the top-performing bike-oriented rail stations in the U.S. Not only has the station experienced a rising share of access trips by bike, but the average distance transit riders have been willing to bike to the station has also risen, from 0.62 miles in 1998 to 1.11 miles in 2008. This 79 percent increase well exceeded the 43 percent increase in average bike-access distance for all BART stations over the same period. Longer biking distances have, in turn, translated into a vastly-enlarged bike access-shed for the Ashby station, as revealed in Figures 2 and 3 for 1998 and 2008, respectively. The maps plot Ashby BART’s bike-sheds for three distance bands: 50, 75, and 95 percentiles. The 75 percentile contour, for example, maps the outer boundary of an isochrone that captures everything from the very shortest to the 75th shortest bike access trips to the station. This means that one-quarter of bike access trips were outside of the 75th percentile access-shed. Similarly, half of bike access trips were beyond the 50th percentile bike-access shed and just 5 percent were beyond the 95th percentile shed.
Figure 2. 1998 access sheds, street patterns, and bicycle infrastructure for Ashby BART station
A visual scan of Figures 2 and 3 shows the amoeba-like bike access-sheds expanded outward for all three distance bands between 1998 and 2008. Table 2 reveals that the estimated land areas (in square kilometers) of the 75th percentile and 95th percentile access-sheds more than doubled over this 10-year period. Thus, not only were there higher shares of patrons accessing Ashby BART by bike in 2008 than 1998, but many were also cycling from considerably further away. If all of the bike-and-riders using Ashby BART in 2008 instead drove cars and used a park-and-ride, an estimated 83,000 additional vehicle miles would have been added to the streets of Berkeley and its surroundings that year.


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<tbody>
<tr>
<td>Bike Access Modal Share</td>
<td>7.4%</td>
<td>11.7%</td>
</tr>
<tr>
<td>Bike Access-shed Size (km²)</td>
<td></td>
<td></td>
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<tr>
<td>50th Percentile</td>
<td>1.5</td>
<td>2.6</td>
</tr>
<tr>
<td>75th Percentile</td>
<td>1.8</td>
<td>4.1</td>
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<tr>
<td>95th Percentile</td>
<td>3.5</td>
<td>7.7</td>
</tr>
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Paralleling the dramatic increases in biking and riding at Ashby BART during the 1998–2008 period were substantial investments in high-quality bicycle infrastructure made by the city of Berkeley around the station. Figures 2 and 3 map the locations of multi-use bike paths, bike lanes (on the shoulders of streets), and bicycle routes (e.g., streets signed and sometimes traffic-calmed for cyclists) surrounding Ashby BART for the two time points. Across the three bike access-shed distance bands, Table 3 shows that the lineal kilometers of bike infrastructure surrounding Ashby BART more than doubled from 1998 and 2008, and the density of bike lanes and paths per km2 jumped as well. Perhaps the most notable infrastructure changes were the openings of Berkeley’s network of bicycle boulevards, several of which flank Ashby as well as the city’s other two BART stations. Bicycle boulevards comfort cyclists with way-finding signs as well as through various traffic calming treatments that divert or significantly slow traffic, such as intersection neck-downs, chicanes, and street tables. They have clearly benefited rail stations. The volume of mid-weekday bicycle traffic at a bicycle boulevard intersection a block and a half away from the Ashby BART station increased by 168 percent between 2000 and 2008 (Weissman 2012). Less than a quarter mile from the station, another bicycle boulevard intersection witnessed a 277 percent gain over the same period.

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<tr>
<td><strong>Bike Infrastructure (lineal km)</strong></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>50th Percentile Bike-shed</td>
<td>2.9</td>
<td>7.9</td>
<td>172.4%</td>
</tr>
<tr>
<td>75th Percentile Bike-shed</td>
<td>3.7</td>
<td>11.1</td>
<td>200.0%</td>
</tr>
<tr>
<td>95th Percentile Bike-shed</td>
<td>6.2</td>
<td>19.7</td>
<td>217.7%</td>
</tr>
<tr>
<td><strong>Bike Infrastructure Densities (lineal km/km²)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>50th Percentile Bike-shed</td>
<td>1.9</td>
<td>3.0</td>
<td>57.9%</td>
</tr>
<tr>
<td>75th Percentile Bike-shed</td>
<td>2.1</td>
<td>2.7</td>
<td>28.6%</td>
</tr>
<tr>
<td>95th Percentile Bike-shed</td>
<td>1.8</td>
<td>2.6</td>
<td>44.4%</td>
</tr>
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</table>

Upon arriving at Ashby BART, a system of ramps facilitates bike access to the station entrance, eliminating the need for cyclists to carry bikes up and down stairs. At the station itself are 136 protected bike-rack parking spaces, 24 secure and enclosed electronic lockers, and a recently-opened self-service bike station that accommodates 128 parked bikes. The racks and lockers were added between the two survey dates. The current count of 288 bike parking spaces at the station proper is 57 percent above what existed in 2001 (BART 2002; Eisen Letunic 2012). In addition, it now costs $1 per day to park a car at Ashby BART, whereas a decade earlier car parking was free.

**Bicycle Access to Fruitvale Bart Station**

Experiences at the other “Urban with Parking” BART station that has recorded appreciable gains in bike access—Fruitvale—tell a similar story. However, unlike the Ashby Station, which caters to significant numbers of university students living in Berkeley, Fruitvale BART lies in what has long been an economically-stagnant district of Oakland, situated midway between downtown and the Oakland International Airport. Neighborhoods surrounding Fruitvale BART are also denser (nearly 25,000 persons per square mile for the census tracts abutting or surrounding the Fruitvale BART station in 2010, compared to 19,500 for tracts adjacent to Ashby BART).
During BART’s first 30 years of operations, the hoped-for transformation of the Fruitvale Station into a viable Transit Village languished and sputtered despite a series of pro-active government efforts to attract new growth and investment (Bennick and Cervero 1997; Cervero et al. 2005). Thanks to a broad-based partnership of public, private, and philanthropic interests and funding support, a compact, mixed-use village huddled around the Fruitvale Station has begun to take form over the past decade (The Unity Council 2012). In keeping with the design principles of successful transit-oriented places (Calthorpe 1993; Cervero et al. 2004), one of the signature features of the Fruitvale Transit Village has been an active public realm that is friendly to pedestrians and cyclists.

As noted previously, Fruitvale posted the largest gain—nearly 10 percentage points—in shares of access trips by bicycle among BART stations from 1998 to 2008. Its estimated bike access-sheds, shown in Figures 4 and 5 and measured in Table 4, also expanded the most. Whereas few residents of the nearby island-city of Alameda biked to Fruitvale BART in 1998, substantial numbers did in 2008, some biking several miles per day each way. Over this 10-year period, the average distance traveled by cyclists heading to Fruitvale BART increased from 1.17 to 1.75 miles, a 50 percent rise.

As part of the Transit Village campaign, a substantial amount of cycling infrastructure has been built around the Fruitvale BART station in the past decade and a half, even more so than around Ashby BART. Table 5 shows that the lineal kilometers of bike paths, bike lanes, and bike routes rose markedly during the 1998–2008 period, as did the density of surrounding bike infrastructure. Some of the surrounding bike-lanes are on heavily-trafficked arterials and, compared to Ashby BART, there is little traffic calming around the Fruitvale Station. But compared to other BART stations in Oakland, neighborhoods around the Fruitvale Station are considerably more bike-friendly. Once inside the Fruitvale Transit Village area, a wide passageway greets cyclists on the north side of the station entrance. Way-finding signs guide cyclists to the station entrance. Within the village and near the station entrance lies a 200-space, high-quality, attended Bike Station, providing secure parking, repair services, and short-term bike rentals. Along with nearby bike racks and lockers, a total of 273 safe and secure bike parking spaces today exist at the Fruitvale Station, an 81 percent increase from the early 2000s (BART 2002; Eisen Letunic 2012). Also, as with the Ashby station, there is a $1 daily charge to park a car and ride BART.
Figure 4. 1998 access sheds, street patterns, and bicycle infrastructure for Fruitvale BART station

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<tr>
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<tbody>
<tr>
<td><strong>Bike Access Modal Share</strong></td>
<td>4.3%</td>
<td>9.9%</td>
<td>5.6% points</td>
</tr>
<tr>
<td><strong>Bike Access-shed Size (km2)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>50th Percentile Bike-shed</td>
<td>2.4</td>
<td>9.4</td>
<td>294.0%</td>
</tr>
<tr>
<td>75th Percentile Bike-shed</td>
<td>4.7</td>
<td>12.0</td>
<td>156.7%</td>
</tr>
<tr>
<td>95th Percentile Bike-shed</td>
<td>6.6</td>
<td>20.6</td>
<td>210.3%</td>
</tr>
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<tbody>
<tr>
<td><strong>Bike Infrastructure (linear km)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>50th Percentile Bike-shed</td>
<td>1.1</td>
<td>10.2</td>
<td>827.3%</td>
</tr>
<tr>
<td>75th Percentile Bike-shed</td>
<td>4.0</td>
<td>13.7</td>
<td>242.5%</td>
</tr>
<tr>
<td>95th Percentile Bike-shed</td>
<td>4.0</td>
<td>18.1</td>
<td>352.5%</td>
</tr>
<tr>
<td><strong>Bike Infrastructure Densities (linear km/km2)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>50th Percentile Bike-shed</td>
<td>0.4</td>
<td>1.1</td>
<td>175.0%</td>
</tr>
<tr>
<td>75th Percentile Bike-shed</td>
<td>0.8</td>
<td>1.1</td>
<td>37.5%</td>
</tr>
<tr>
<td>95th Percentile Bike-shed</td>
<td>0.6</td>
<td>0.9</td>
<td>50.0%</td>
</tr>
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“Worst Case” Experience

Case-based studies as above offer advantages of transparency and real-world insights; however, they rarely provide enough quantitative ammunition to draw probabilistic inferences and make causal statements, at least in a strict sense. To strengthen the internal validity of case-based methods, best-case examples like the Ashby and Fruitvale Stations are sometimes contrasted with “worst case” examples (Yin 1994). As noted earlier, the “worst case” experience in attracting cyclists among BART stations that are “Urban with Parking” is Balboa Park BART in the city of San Francisco (see Figure 1). The term “worst” is comparative since even though Balboa Park’s 1.9 percent bike modal split was the lowest among “Urban with Parking” stations in 2008, relative to all BART stations, this modal split was in the middle of the pack and relative to many other rail stations across the U.S., this is a respectable figure. Moreover, the Balboa Park Station recorded a 1.2 percentage point gain
in the share of access trips by bike over this 10-year period. It should be noted as well that Balboa Park’s relatively modest levels of bicycle access and egress are likely due, in part, to factors that encourage transit access, including high-quality feeder bus services with discounted transfers. Nonetheless, among BART’s “Urban with Parking” stations, it was the least popular with cyclists.

The increase in bike-access modal shares at Balboa Park BART is likely associated with increases in on-site bike parking, from 47 spaces in 2001 to 100 spaces today (BART 2002; Eisen Letunic 2012). Unlike the Ashby and Fruitvale Stations, however, there is no full-service bike station at Balboa Park BART. Where the Balboa Park station most markedly differs from the two best-case examples is in the amount of bike infrastructure built off-site. Figures 6 and 7 map bicycle infrastructure as well as the three bands of bike access-sheds for Balboa Park BART in 1998 and 2008. Comparatively modest amounts of bicycle infrastructure were built around the Balboa Park station over this 10-year period, which was matched by geographically-constrained bike access-sheds that did not expand much over this period. In 2008, Balboa Park BART had around one-third as many lineal kilometers of bike paths and bike lanes within its 75th and 95th percentile bike access-sheds as did the Ashby and Fruitvale stations.

In sum, the Balboa Park Station recorded a respectable gain in bike access modal shares over the study period; however, its bike access-shed did not grow nearly as much as those of the Ashby and Fruitvale stations. On-site bicycle parking improvements likely encouraged more nearby residents to bike-and-ride, but the minimal amount of off-site bicycle infrastructure that was built failed to enlarge the station’s bike access-shed and draw in more bike customers.
Figure 6. 1998 access sheds, street patterns, and bicycle infrastructure for Balboa Park BART station.
Figure 7. 2008 access sheds, street patterns, and bicycle infrastructure for Balboa Park BART station
Conclusion
This paper’s case experiences largely tell a story of “build it and they will come.” If bicycles are to play a significant mobility role for accessing rail stations in the U.S., safe, secure, and well-designed bicycle infrastructure will be needed. This conclusion, drawn from case-based assessments, is supported by other research that has stressed the importance of separate, protected facilities in encouraging cycling more broadly (Dill and Voros 2007; Krizek et al. 2007; Buehler and Pucher 2012). It is also consistent with a recent regression-based model prepared for BART that showed, among the system’s 42 stations, the presence of bike stations and increases in bike rack and electronic locker spaces were statistically associated with increased bicycle access trips to BART (Fehr and Peers 2012). Such improvements are not “amenities” but rather basic “provisions,” not unlike the provisions for safe and convenient facilities provided to park-and-riders. Dutch and Danish cities show that directing significant shares of municipal budgets into bicycle and pedestrian improvements translates into significant shares of trips being made by non-motorized modes (Beatley 2000; Cervero 2003).

Some have noted that bike-and-ride becomes problematic when it is most successful (Pucher and Buehler 2009). Cities with high transit usage and levels of cycling face on-board capacity constraints. In contrast to the U.S., where the majority of cyclists take their bikes on board, in Europe cyclists mostly park their bikes at stations. The provision of ample, sheltered, secure bike parking at stations encourages this (Pucher and Buehler 2008), as does bike-sharing at destination stations.

Bicycles can and, we would argue, should play a stepped-up role in providing access to rail stations in many parts of the U.S. Money freed up from not having to expand park-and-ride facilities is one obvious funding source. So are regional, state, and federal funding programs that aim to improve urban air quality or promote sustainable mobility more broadly. Part of the success at the Ashby and Fruitvale Stations lies in collaborative efforts among multiple stakeholder interests. This took the form of the rail agency itself coordinating activities with bicycling and environmental advocacy groups and surrounding municipalities to plan, design, and build high-quality bike infrastructure, on-site and near-site. In the case of the Fruitvale station, bicycling improvements were part of a larger urban-regeneration campaign to build a vibrant, mixed-use transit village. As is often the case in the urban transportation field, the “hardware” component of high-quality bicycle facilities was matched by supportive “software,” notably effective collaborations among
stakeholder interests, to make bike-and-ride a respectable option for accessing rail stops.

**Acknowledgement**

We thank Val Menotti of BART for making survey data available to support this study. We also thank Bruce Appleyard for his help in conceptualizing bike access-sheds.

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Simulation-Based Regression Models to Estimate Bus Routes and Network Travel Times

Yaser E. Hawas, United Arab Emirates University

Abstract

This paper presents an approach to estimate bus route and network travel times using micro-simulation. This can be used in predicting the effectiveness of bus route designs using some network traffic measures or indicators. The used indicators are average network traffic intensity, posted speeds, route length, frequency of bus operation, and average passenger loadings (boarding and alighting). Regression models are calibrated to predict both route and overall network travel times. The prediction errors of these models were investigated and analyzed, and regression models were validated. Results indicated the validity of the calibrated regression models. Conclusions are made on how the devised models can be validated in reality and used for route planning purposes to determine best operating conditions such as the frequency.

Introduction

The performance of a transit network depends on the effective planning and design of transit routes. To ensure effective planning of transit networks, it is important to develop tools or methods to characterize network effectiveness as a function of frequency, route design, and other factors such as traffic network intensity and passenger loadings. Such methods or tools are eventually needed to assist transport agencies in transit planning applications, alteration of service...
schedules, devising of enhancement policies, macro-management of operation, and, ultimately, better service for transit users.

Transit effectiveness measures are needed to quantify how efficiently transit system inputs are used in producing a given output (Nash 2006). Among the common effectiveness indicators of transit network design are the overall network and route travel times. The lesser the travel times of the designs needed to provide service to specific transit demand, the better is the design and the more attractive is the service to transit users. The effectiveness indicators are influenced by many factors, such as number of bus stops on routes, number of passengers boarding and alighting, speed restrictions, route length and alignments, etc.

In general, the factors that affect travel times include human, vehicular, and facility aspects. Different drivers and road conditions could cause large differences in journey times. For the same time interval and on the same link, different vehicles can have quite different travel times (Li and McDonald 2002). Free-flow travel speed is another factor that affects network travel time. Journey speed along an arterial road depends not only on the arterial road geometry but also on the traffic flow characteristics and traffic signal coordination (Lum et al. 1998). Other main factors cited in previous studies include incidents (Karl et al. 1999), signal delay (Wu 2001), weather conditions (Chien and Kuchipudi 2003), and traffic congestion levels (Lin 2005). Speed (Chien 2003), frequency, and number of boarding and alighting passengers of bus service (Tetreault 2010) have been used for route and network average travel time prediction.

The use of travel time information is essential for long-term design of transit service as well as scheduling. In relatively stable light traffic conditions, with light transit demand, fairly simple estimation procedures may be used to estimate travel times. On the other hand, in rapidly-changing traffic conditions, using sophisticated prediction models is essential (Van Grol et al. 1999). Different studies suggested different techniques for estimating or predicting travel times (Kwon et al. 2003; Chakraborty and Kikuchi 2004; Zhang and Rice 2003; El-Geneidy et al. 2010; Tetreault and El-Geneidy 2010).

Simulation-based regression models were used to predict run time, schedule adherence, and reliability of the transit route (El-Geneidy et al. 2010; Tetreault and El-Geneidy 2010). Predicted travel times using artificial neural networks have been found to be more accurate than the other methods (Waller et al. 2007). Huisken and Van Berkum (2003) developed a travel time prediction method based on artificial neural networks and compared them with the currently-used travel time prediction model for a corridor in the Netherlands. Van Lint et al. (2002) used recurrent neural networks to predict freeway travel time. Van Lint (2003) extended this work to develop an approach to quantify the uncertainty around the travel time predictions. Mark et al. (2004) conducted a comprehensive statistical analysis of the impact of various factors, such as temporal resolution of the data, speed, and flow on the experienced travel time predictions obtained using artificial neural networks in the presence of incidents. The data for this study were synthetically generated by simulation using a Cell Transmission Model as the traffic flow model.

Many researches used the Kalman Filtering (KF) algorithm for predicting travel time (Nanthawichit et al. 2003; Kuchipudi and Chien 2003; Chien and Kuchipudi 2003; Chen and Chien 2001). The KF algorithm was first applied by Okutani and Stephanedes (1984) to predict traffic volumes in an urban network. Nanthawichit et al. (2003) developed a method for short-term travel time prediction by combining a KF approach with a macroscopic traffic flow model. Kuchipudi and Chien (2003) developed a model in which both path-based data and link-based data are used to predict travel times using a KF framework. Chien and Kuchipudi (2003) used a KF algorithm for short-term prediction of travel time; the study used a combination of historical and real-time data. Chen and Chien (2001) used the KF technique for dynamic travel time prediction based on real-time probe vehicle data.

Simulation has become a popular and effective tool for analyzing a wide variety of dynamic problems that are associated with complex processes (Ni 2001). In the transportation field, the application of simulation is widely extending from small applications such as traffic signal optimization to wide-scale applications such as evaluating the national transport strategy. Simulation can capture statistics on the variability of the characteristics (Fishburn and Taaffe 1994). Several researchers have used simulation to generate traffic data (Anderson and Bell 1998). Chien and Kuchipudi (2003) used traffic simulation to develop a model for predicting travel times based on spot speed/volume data obtained from sensors on a freeway corridor. The spot speed/volume data were used to calibrate a traffic simulation model. The simulated travel times were fed into a KF framework to predict the future
travel times. Fernández (2010) developed a microscopic simulation model for the study of operations at public bus and light rail stops. Shalaby and Farhan (2003) developed microscopic simulation model to predict the travel time of public transport vehicles using automatic vehicle location data and automatic passenger counters; they used the KF algorithm to predict running time and dwell time of vehicles, and model verification was carried out using simulated data from VIS-SIM software. Zhang et al. (2008) developed some alighting and boarding micro-simulation model for passengers in Beijing metro stations. Toledo et al. (2010) used a mesoscopic simulation model for the evaluation of operations, planning, and control. Kachroo et al. (2001) developed travel time functions based on macroscopic models of highways. Burghout et al. (2005) developed a hybrid mesoscopic-microscopic model that applies microscopic simulation to areas of specific interest while simulating a large surrounding network in lesser detail with a mesoscopic model; the hybrid model integrates MITSIMLab, a microscopic traffic simulation model, and Mezzo, a mesoscopic traffic simulation model. Other used hybrid models include Hystra (Bourrel and Lesort 2003) and Micro-Macro link (Helbing et al. 2002), which combine dynamic macro with micro simulation.

Traditional macroscopic models are generally ineffective in evaluating strategies designed to influence travel choices and optimize system performance (Sbayti and Roden 2010). If the purpose of the study is to address congestion problems with operational and management strategies, microscopic models are much better positioned than macroscopic models to evaluate the effectiveness of the alternatives. While micro simulation models are definitely desirable, they require details about transportation facilities and flow entities at a granularity that is not typically available to transport agencies (Sbayti and Roden 2010).

In this paper, we propose an integrated approach that uses the microscopic model I-SIM-S (Hawas 2007a) to generate detailed levels of data on the facilities and flow entities that then can be used to characterize the effectiveness of bus route design in urban traffic networks. The adopted methodology entails using I-Sim-S to simulate different scenarios reflecting various network traffic intensities, posted speeds, route lengths, frequencies of bus operation, and average passenger loadings (boarding and alighting). The simulated scenarios are used to estimate the route effectiveness measures—namely, the bus route travel time and overall network travel time measures. This is then followed by developing regression models using the simulation-based effectiveness measures data. The developed models are then validated and assessed.
This paper consists of seven sections. The next section briefly reviews the features of the I-SIM-S micro simulator and presents the simulation-based experimental scenarios. The simulation results are analyzed in the following section, followed by presentation of the calibrated regression models. Validation of the regression models is highlighted, and conclusions and future research directions are highlighted.

**Experimental Setup**

I-SIM-S is an object-oriented program that allows for virtual detector installations at different locations and models different intersection layouts, traffic control types and timing, and link characteristics. It includes objects such as streets, lanes, detectors, vehicles, signals, and intersections, and each object is composed of data that represent the current values of object parameters and methods (or functions) that could be applied on the object (for example, add vehicle or remove vehicle for the lane object). The program is a hierarchical model in the sense that main or larger objects contain the sub (or smaller) objects; for example, each street object contains several lane objects, and each of these lane objects contains the vehicle objects (Hawas 2007a). I-SIM-S has extended capabilities to model and/or identify incidents accurately through multiple loop detectors on links of urban intersections. These capabilities were used to develop a fuzzy logic model for incident detection (Hawas 2007b). The I-Sim-S car-following model is coupled with a finite-state model that captures the lane switching behavior of the driver. The model also has the ability to capture lane switching when the lead vehicle is a bus stopping in a bus bay for boarding and alighting passengers. For more details on the I-Sim-S structure, mathematical formulation, and calibration, the reader is referred to Hawas (2007a). The simulator has been validated versus well-known microscopic simulators and in reality (Hawas and Abdul Hameed 2009).

One hypothetical network with 49 nodes, 14 origins, and 24 destinations was created for testing. The hypothetical network links were bidirectional with the same posted (free-flow) speed. All intersections were operated with pre-timed controllers. As shown in Table 1, the test scenarios were generated with four network configurations (different link lengths), four O-D flow patterns, two posted link speeds, three bus frequencies, and three levels of passenger loading.
Table 1. Simulation-based Experimental Scenarios

<table>
<thead>
<tr>
<th>Link Length (m)</th>
<th>Source Node Volume (veh/hr)</th>
<th>Posted Link Speed (km/hr)</th>
<th>Frequency (#buses/hr/ route)</th>
<th># Passengers Boarding (or Alighting) per Hour at Each Bus Stop</th>
</tr>
</thead>
<tbody>
<tr>
<td>H (300), V (300)</td>
<td>500</td>
<td>60</td>
<td>2</td>
<td>50, 150, 300</td>
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<td></td>
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<td>2000</td>
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<td>18 scenarios</td>
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<tr>
<td>H (500), V (500)</td>
<td></td>
<td></td>
<td></td>
<td>72 scenarios</td>
</tr>
<tr>
<td>H (500), V (300)</td>
<td></td>
<td></td>
<td></td>
<td>72 scenarios</td>
</tr>
<tr>
<td>H (500), V (500)</td>
<td></td>
<td></td>
<td></td>
<td>72 scenarios</td>
</tr>
</tbody>
</table>

H = length of horizontal link (m); V = length of vertical link (m)

The first column illustrates the values of the network link lengths used in the various scenarios. In these scenarios, horizontal and vertical link lengths are set as H (300), V (300); H (300), V (500); H (500), V (300), and H (500), V (500). The second column illustrates the source nodes demand volumes. Four different demand patterns are used generating 500, 1,000, 1,500, and 2,000 veh/hr at each of the 14 source (origin) nodes. In all tested scenarios, the source volumes were equally
distributed among all 24 possible destinations. These demand levels represent light
to congested traffic conditions. The third column illustrates the link posted speed
for all tested scenarios. Two speed limits of 60 and 80 km/hr were considered.
The fourth column illustrates the bus frequencies used in the various simulation
experiments. Three different bus frequencies (namely, 2, 3, and 4 buses/route) were
tested. The last (fifth) column shows the number of passengers boarding (or alighting) per hour at each bus stop; three different levels were used (50, 150, and 300 passengers/hour). A total of 288 testing scenarios were generated (4 link lengths scenarios × 4 source volume levels × 2 speed scenarios × 3 bus frequencies × 3 boarding-alighting passenger levels).

At the beginning of the analysis period, details of the network structure, connectivity
and characteristics, signal characteristics, and settings over the analysis period were
provided as inputs to I-Sim-S simulator. The shortest path algorithm was “called” at
the beginning of each cycle. Each vehicle (when generated) was assigned an O-D pair
(in accordance with a pre-specified O-D matrix for the entire network). The generated
vehicle is assigned the most recent shortest path of the O-D pair. Whenever a vehicle
reaches the end of a link, its direction is determined according to its assigned path.

Table 2 shows a sample of the I-SIM-S output file for a test scenario with a total
analysis period of 120 minutes, in a 49-node network. The link lengths for the tested
grid network are 500 meters for the horizontal links and 300 for the vertical links.
The posted speed in the network is set to 60 km/hr. The source node hourly volume
is set to 1000 veh/hr for each source node. The frequency of bus is set to 3 buses
per hour on each route. The passengers boarding and alighting at each bus stop are
set to 50 and 50 passengers per hour, respectively.

Table 2 illustrates the output of route R1 (as denoted in the first column). The
second column provides the bus number (BN) for each bus entering the network
along R1. The number of entering buses depends on the frequency of buses per
hour. For the tested scenario, with a frequency of three (3), and given an analysis
period of 120 minutes, a total of six buses entered the network; five of which com-
pleted the trips (and as such their names were denoted by the status C letter) and
one trip was incomplete by the end of the analysis period (denoted by the status I
letter). The buses with incomplete trips were excluded from the calculation of aver-
age travel times. The third column presents the bus entry time into the network
(ETN). This variable also depends on the frequency of bus per hour. According to
the used frequency of three (3), on average a new bus will enter into the network
every 20 minutes. Each operating bus on route R1 has six stops (S1 through S6) as
shown in the fourth column. The fifth column shows the stopping time at each stop (ST). The total stopping time (TST) of one bus along the route is presented in the sixth column, and it is estimated by adding the stopping times on all the bus stops. The seventh column presents the estimated total running time (TRT). The eighth column shows the total travel time (TT).

Table 2. Simulation-Based Bus Performance Output

<table>
<thead>
<tr>
<th>Route</th>
<th>BUS No. 1_C</th>
<th>BN</th>
<th>ETN</th>
<th>BS</th>
<th>ST (min)</th>
<th>TST (min)</th>
<th>TRT (min)</th>
<th>TT (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>R1</td>
<td>0.02</td>
<td>BS1</td>
<td>0.85</td>
<td>BS2</td>
<td>0.88</td>
<td>5.04</td>
<td>32.94</td>
<td>37.98</td>
</tr>
<tr>
<td></td>
<td></td>
<td>BS3</td>
<td>0.92</td>
<td>BS4</td>
<td>0.85</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>BS5</td>
<td>0.77</td>
<td>BS6</td>
<td>0.77</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>19.98</td>
<td>BS1</td>
<td>0.92</td>
<td>BS2</td>
<td>0.8</td>
<td>5.1</td>
<td>33.02</td>
<td>38.12</td>
</tr>
<tr>
<td></td>
<td></td>
<td>BS3</td>
<td>0.83</td>
<td>BS4</td>
<td>0.92</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>BS5</td>
<td>0.75</td>
<td>BS6</td>
<td>0.88</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>39.98</td>
<td>BS1</td>
<td>0.82</td>
<td>BS2</td>
<td>0.9</td>
<td>5.1</td>
<td>31.6</td>
<td>36.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>BS3</td>
<td>0.8</td>
<td>BS4</td>
<td>0.93</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>BS5</td>
<td>0.8</td>
<td>BS6</td>
<td>0.85</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>59.98</td>
<td>BS1</td>
<td>0.83</td>
<td>BS2</td>
<td>0.92</td>
<td>5.15</td>
<td>32.28</td>
<td>37.43</td>
</tr>
<tr>
<td></td>
<td></td>
<td>BS3</td>
<td>0.82</td>
<td>BS4</td>
<td>0.82</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>BS5</td>
<td>0.83</td>
<td>BS6</td>
<td>0.93</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>79.98</td>
<td>BS1</td>
<td>0.85</td>
<td>BS2</td>
<td>0.85</td>
<td>5.24</td>
<td>30.58</td>
<td>35.82</td>
</tr>
<tr>
<td></td>
<td></td>
<td>BS3</td>
<td>0.92</td>
<td>BS4</td>
<td>0.85</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>BS5</td>
<td>0.97</td>
<td>BS6</td>
<td>0.8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>99.98</td>
<td>BS1</td>
<td>0.88</td>
<td>BS2</td>
<td>0.85</td>
<td>2.65</td>
<td>15.13</td>
<td>17.78</td>
</tr>
<tr>
<td></td>
<td></td>
<td>BS3</td>
<td>0.92</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>BUS No. 6I*</td>
<td>BS1</td>
<td>0.88</td>
<td>BS2</td>
<td>0.85</td>
<td>2.65</td>
<td>15.13</td>
<td>17.78</td>
</tr>
<tr>
<td></td>
<td></td>
<td>BS3</td>
<td>0.92</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Average Bus Performance 5.13 32.08 37.21
Analysis of Data

Figure 1 shows the variation of the average stopping time for different source volume level, various levels of passenger loading, and bus frequencies. It shows that increasing the passenger loading level increases the bus stopping time, whereas increasing the bus frequency decreases the average bus stopping time. The figure also illustrates that the source volume has no effect on bus stopping time.

Figure 1. Average bus stopping time (mins) for network of horizontal and vertical link lengths of 300 and 300 m, link speed of 60 km/hr, under various source volumes and (a) frequency: 2 buses/hr, and (b) bus frequency: 4 buses/hr
Figure 2 shows the average bus stopping time (minutes) for various bus frequencies and passenger loading levels [for the network of horizontal and vertical link lengths of 300 and 300 meters, source volume of 500 veh/hr, link speeds of 60 km/hr]. It clearly illustrates that the average bus stopping time is affected by the bus frequencies and the passenger loading levels. The higher the bus’s frequency, the lesser the bus’s stopping time. On the other hand, the higher the passenger loading level, the higher the bus’s stopping time.

Figure 3 shows the average bus total travel time (minutes) for various link speeds, for the network of horizontal and vertical link lengths of 300 and 300 meters, source volume of 500 veh/hr, link speeds of 60 and 80 km/hr, and (a) frequency: 2 buses/hr, (b) bus frequency: 3 buses/hr and (c) bus frequency: 4 buses/hr.
Figure 3. Average bus total travel time (mins) for network of horizontal and vertical link lengths of 300 and 300 m, source volume of 500 veh/hr, link speeds of 60 and 80 km/hr, and (a) frequency: 2 buses/hr, (b) bus frequency: 3 buses/hr, and (c) bus frequency: 4 buses/hr
Figure 4 shows the variation of the network average travel time for different source volume level, and various link speeds. Increasing source volume increases the average network travel time, whereas the increasing speed decreases the average network travel time.

![Bar chart showing average network travel time for various source volumes and link speeds](image)

**Figure 4. Average network travel time (in mins) for various source volumes and link speeds (bus frequency of 3 buses/hr and 150 passengers/hr boarding/alighting at each bus stop)**

**Calibration of Regression Models**

The 288 cases/scenarios were simulated by I_Sim_S and used in developing linear regression models. Two linear regression models were developed to estimate the average bus route travel time and the overall network travel time.

The independent variables considered for regression analysis included total route length (m), speed (km/hr), frequency (buses/hr/route) (Chien 2003), average network intensity (veh/km), and number of passenger boarding and alighting/hr on an average route (Tetreault 2010).

The route length is the number of links per route times the length of each link. The average network intensity was calculated by dividing total network volume by total network length multiplied by number of lanes. Total network volume is number of source nodes times source volume per O-D pair. The study considered 14 source nodes, 4 different source volume levels, and 3 lanes per link. The total number of passengers boarding/alighting per hour on an average route was calculated by
multiplying number of passengers per stop by number of bus stops on the route, summed over all routes and then divided by number of routes. Four different levels of passenger loadings, four routes and six bus stops per route were considered for the test network. Table 3 shows the independent and dependent variables for the two regression models.

**Table 3. Independent and Dependent Variables for Regression Analysis**

<table>
<thead>
<tr>
<th>Model</th>
<th>Independent Variables</th>
<th>Dependent Variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>I (ABTT)</td>
<td>Route length (m) (X1)</td>
<td>Average bus travel time (Y)</td>
</tr>
<tr>
<td></td>
<td>Average network intensity (veh/lane.km) (X2)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Speed (km/hr) (X3)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Frequency (buses/hr/route) (X4)</td>
<td></td>
</tr>
<tr>
<td></td>
<td># passengers boarding/alighting per hr on average route (X5)</td>
<td></td>
</tr>
<tr>
<td>II (NATT)</td>
<td>Total network length (m) (X6)</td>
<td>Network average travel time (Z)</td>
</tr>
<tr>
<td></td>
<td>Average network intensity (veh/ lane.km) (X7)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Speed (km/hr) (X8)</td>
<td></td>
</tr>
</tbody>
</table>

Several iterations were done for calibrating Network Average Travel Time (NATT) model by excluding the insignificant variables. First, the linear regression model was run using five variables. It was concluded to include only the three variables shown in Table 3, based on the goodness-of-fit test (t-stat greater than 2). Two variables (percentage of buses in the network and passengers loading level) were excluded. The coefficients and the t-stat values for the final two models are summarized in Table 4.

The R-square values for both Average Bus Travel Time (ABTT model) and Network Average Travel Time (NATT model) are quite reasonable. The standard error for ABTT model is higher than that of the NATT model. The goodness-of-fit tests indicate that all the independent variables in both models are statistically significant (with t-stat greater than 2 and the p-values lesser than 0.05). The intercept values (a0 and b0) for the ABTT and NATT models are relatively high with good statistical significance values. This indicates the need to include more independent variables in both models.
Table 4. Coefficient Values and Goodness-of-Fit Measures (ATT and NATT)

<table>
<thead>
<tr>
<th>ABTT Model</th>
<th>Coeff</th>
<th>t-stat</th>
<th>p</th>
<th>NATT Model</th>
<th>Coeff</th>
<th>t-stat</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>a0</td>
<td>46.727</td>
<td>15.08</td>
<td>4.21E-38</td>
<td>b0</td>
<td>8.77</td>
<td>15.304</td>
<td>5.719E-39</td>
</tr>
<tr>
<td>a1</td>
<td>0.002</td>
<td>7.827</td>
<td>1.01E-13</td>
<td>b6</td>
<td>0.003</td>
<td>21.583</td>
<td>7.996E-62</td>
</tr>
<tr>
<td>a2</td>
<td>0.007</td>
<td>2.392</td>
<td>0.017392</td>
<td>b7</td>
<td>0.012</td>
<td>19.742</td>
<td>3.295E-55</td>
</tr>
<tr>
<td>a3</td>
<td>-0.149</td>
<td>-5.06</td>
<td>7.49E-07</td>
<td>b8</td>
<td>-0.07</td>
<td>-12.53</td>
<td>5.959E-29</td>
</tr>
<tr>
<td>a4</td>
<td>-6.39</td>
<td>-17.8</td>
<td>1.7E-121</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a5</td>
<td>0.020</td>
<td>41.26</td>
<td>1.7E-121</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Standard Error

|       | 4.97857 | 0.96365 |

R-square

|       | 0.88193 | 0.73362 |

The regression analysis predicted the signs of all coefficients logically. For example, if the length of the route (X1) is increased, the average bus travel time (Y) will increase (the a1 coefficient is positive). Similarly, if the total network length (X6) is increased, the network average travel time (Z) will increase (the b6 coefficient is positive). On the other hand, increasing the route’s average speed (X3) will result in decreasing the average bus travel time (Y) (the a3 coefficient is negative). The calibrated regression ABTT and NATT models are given below:

\[ Y = 46.727 + 0.002X_1 - 0.007X_2 - 0.149X_3 - 6.398X_4 + 0.020X_5 \]  
\[ Z = 8.771 + 0.0002X_6 + 0.012X_7 - 0.071X_8 \]

All coefficient values are rounded up to three decimal places.

Residuals Analyses for Calibrated Models

The residuals were calculated as the difference between observed (extracted from the I-SIM-S simulator) and estimated values (from the regression models). Figure 5 shows the percentages of deviations between the simulation-based observed and the estimated values using the ABTT model. The negative and positive deviations represent 54 percent and 46 percent of the 288 scenarios, respectively. The average deviation is 0.66 percent, with the maximum and minimum deviations to be around 27 percent and -43 percent, respectively. A total of 252 scenarios (about 88% of the scenarios) exhibited values of deviation equal to or less than 15 percent. Only 36 scenarios (12%) have deviation values more than 15 percent. This means
that the ABTT regression model can be used for prediction, with an expected prediction error of 15 percent or less in 88 percent of the cases that the model is applied for. This is quite acceptable accuracy level for the purpose of planning/design of routes. The remaining 12 percent of the cases resulted in error values ranging between 15–30 percent. This suggested the probable need to include more independent variables.

Figure 5. Percentages of deviations between predicted (using ABTT model, Eq. 1) and observed (i-SIM-S simulated) values of average bus travel time (for 288 calibration scenarios)

Figure 6 shows the percentages of deviations between observed and estimated values using the NATT model. The negative and positive deviations (errors) represent 55 percent and 45 percent of the 288 scenarios, respectively. The average deviation is -0.49 percent, with the maximum and minimum deviations to be around 13 percent and -13.9 percent, respectively. Only 55 scenarios (about 19% of the 288 scenarios) resulted in deviations more than 10 percent. This means that the NATT regression model can be used for prediction, with an expected prediction error of 10 percent, or less in 81 percent of the cases to which the model is applied. This is quite acceptable accuracy level for the purpose of planning/design of routes. It should be noted that the literature of the travel time prediction models indicates relatively larger error values. For instance, Shalaby and Farhan (2003) reported mean of error values ranging from 3–8 percent average error values (with a max error value of 23%) on individual links using the KF approach and a mean of error values ranging from 8–22 percent average error values (with a maximum error
value of 46%) on individual links on individual links using the regression modeling approach. The average deviation of the presented NATT model (-0.49%) with a maximum error of 13.9 percent is far below the reported models in Shalaby and Farhan (2003).

![Figure 6. Percentage of deviation between predicted (using NATT model, Eq. 2) and observed (I-SIM-S simulated) values of network average travel time (for 288 calibration scenarios)](image)

**Validation of ABTT and NATT Models**

The simulation model I-SIM-S was further used to generate 64 validation scenarios. These validation scenarios were generated with independent variable values different from those used in developing the 288 calibration scenarios (previously described in Table 1). Table 5 shows the values of the independent variables used in generating the validation scenarios. The rationale is to check the accuracy of the developed (ABTT and NATT) regression models in predicting the average bus travel time and the network average travel time in cases beyond those used in the calibration of these models.
Table 5. Values of Variables Considered for Validation Scenarios

<table>
<thead>
<tr>
<th>Link Length (m)</th>
<th>Source Node Volume (veh/hr)</th>
<th>Posted Link Speed (km/hr)</th>
<th>Frequency (#buses/hr/route)</th>
<th># Passengers Boarding (or Alighting) per Hour at Each Bus Stop</th>
</tr>
</thead>
<tbody>
<tr>
<td>H (400 m)</td>
<td>750 veh/hr</td>
<td></td>
<td>1</td>
<td>200</td>
</tr>
<tr>
<td>V (400 m)</td>
<td>(16 scenarios)</td>
<td></td>
<td>2</td>
<td>200</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3</td>
<td>400</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>4</td>
<td>400</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>5</td>
<td>200</td>
</tr>
<tr>
<td></td>
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<tr>
<td></td>
<td>90</td>
<td></td>
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<td>200</td>
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<td>2</td>
<td>200</td>
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<td></td>
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<td>3</td>
<td>400</td>
</tr>
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<td></td>
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<td></td>
<td>4</td>
<td>200</td>
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</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>400</td>
</tr>
<tr>
<td>H (600m)</td>
<td>1750 veh/hr</td>
<td>70</td>
<td>1</td>
<td>200</td>
</tr>
<tr>
<td>V (600m)</td>
<td>(32 scenarios)</td>
<td></td>
<td>2</td>
<td>200</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3</td>
<td>400</td>
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<td>200</td>
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</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>400</td>
</tr>
</tbody>
</table>

Similar to the calibration scenarios, the validation experimental setup accounts for the variations in link lengths (column 1), O-D demand pattern represented by the source node volume (column 2), posted link speeds (column 3), bus frequency (column 4), and number of boarding and alighting passengers (column 5).

Two link lengths, two patterns of O-D flows, two speed limits, five bus frequencies, and two passenger loading levels were used in developing the validation scenarios, as shown in Table 5. It is important to note that these values are different than those used in calibration (previously shown in Table 1).

The above 64 validation scenarios were run by the simulator (I-SIM-S) to obtain the observed values of the average bus travel time and the network average travel time.
Furthermore, the developed regression models (ABTT and the NATT) were used to estimate the corresponding Y and Z values. The observed and estimated values were then used to carry on detailed residual analyses.

**Residuals Analyses for Validation Scenarios**

Figure 7 shows the percentages of deviations between the simulation-based observed and the estimated values using the ABTT model for all validation scenarios. The negative and positive deviations represent 52 percent and 48 percent of the 64 validation scenarios, respectively. The average deviation is 0.12 percent, with the maximum and minimum deviations to be around 33 percent and -24 percent, respectively. A total of 18 scenarios out of the 64 (about 28%) exhibited deviation values of more than 15 percent, as compared to 12 percent of the calibration scenarios with similar deviation values (as shown in Figure 5).

![Figure 7. Percentages of deviations between predicted (using ABTT model, Eq. 1) and observed (I-SIM-S simulated) values of average bus travel time (for 64 calibration scenarios)](image)

Figure 8 shows the percentages of deviations between the simulation-based observed and the estimated values using the NATT model for all validation scenarios. The negative and positive deviations represent 92.2 percent and 7.8 percent of the 64 validation scenarios, respectively. The average deviation is 12 percent, with the minimum deviations to be around -27 percent. A total of 44 scenarios out of the 64 (about 68%) exhibited deviation values of 15 percent or less.
Figure 8. Percentage of deviation between predicted (using the NATT model, Eq. 2) and observed (I-SIM-S simulated) values of network average travel time (for 64 calibration scenarios)

Conclusions and Future Work

This paper presents an approach to characterize bus route design using micro-simulation and to predict the effectiveness of bus route designs using some general network measures and traffic indicators. The used indicators are average network traffic intensity, posted speeds, route length, frequency of bus operation, and average passenger loadings (boarding and alighting).

The developed models differ from those reported in the literature to predict travel times in several aspects. It explicitly captures bus operation rather than a general travel time prediction model for all vehicles in the network. Additionally, the developed regression models are simple, with few variables that can be developed/validated using field data if such data become readily available. The use of the detailed microscopic simulator for data generation and study of various scenarios enables developing a generalized model that can be applied to wide range of bus operation characteristics, instead of using limited field data. It also enables more accurate modeling and traffic measures and, therefore, better model validity. This is evident in the resulting acceptable validation error.

Regression models were calibrated and validated to predict both route and overall network travel times. The presented validation process is simulation-based. More work is still to be conducted for real-life validation. To validate the devised cali-
bration models in reality, data representing the independent variables of the two regression models need to be gathered. For instance, for the ABTT model, two particular independent variables (X2 and X5) will have to be measured through field surveys at bus stops and link traffic counts. Surveys should be conducted on a sample of operating bus routes during peak hours to count the number of passengers boarding/alighting at each bus stop. This will be used to estimate the average route ridership per hour (X2). For a network of N links, a sample of n links need to be randomly selected. The n value should be estimated using a sample size formula for a population of N links, according to a specific significance level and percent of error. On the randomly selected n links traffic counts should be done during the same peak hours during which the passenger surveys are instrumented. These link traffic counts can be used then to estimate the value of the average network intensity (X5). The other independent variables (X1, X3 and X4) can be easily measured also in reality or obtained directly from the operating bus agency itself. The observed independent variables can then be used for validating the ABTT model. Comparing actual bus trip times on surveyed routes with those estimated from the ABTT model using the field estimated independent variables (X1 through X5) can be used for assessing model accuracy. The NATT model can also be validated in reality using a similar approach. The X7 variable of the NATT model is similar (equivalent) to the variable X5 of the ABTT model. Currently, case study data are being collected for the operating bus routes of Al Ain and Abu Dhabi in the UAE. This will help determine whether the operating bus frequencies and route design are efficient.

The devised models can be used for route planning purposes to determine the best operational route characteristics such as bus frequency. Bus agencies can find the application of the two devised model quite beneficial to assess the efficiency of their operating routes. Also, the Y and the Z values of the ABTT and NATT models can be used further to develop some simplified mode split models to capture the effect of route design and bus frequencies on bus ridership. This could be an interesting application for these models that will allow agencies to obtain estimates of how changes in route design or operation will likely affect the market segment of bus users. This will be investigated in further research.
Acknowledgments

This work was funded by the Roadway, Transportation and Traffic Safety Research Center (RTTSRC) at UAE University. The author would like to acknowledge Eng. Nandita Basu, a former research assistant at RTTSRC, for her valuable assistance.

References


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Ridership and Revenue Implications of Free Fares for Seniors in Northeastern Illinois

Paul Metaxatos, University of Illinois at Chicago

Abstract

This paper reports on the ridership and revenue impacts for transit providers of a short-lived Seniors Free Ride Program in the Chicago metropolitan area. The discussion presents survey-free and survey-based approaches specifically developed to capture such effects during the program implementation. The analysis shows that instituting a free fare policy for seniors expectedly increased the demand for and associated costs of providing the service. In particular, the program had attracted approximately 75 percent additional senior rides at an associated cost of between $26.1 and $78.6 million. The Illinois legislature modified the program in 2011 to run as a means-tested program partially because of cost considerations. However, the methodology presented remains relevant for existing and future fare-free programs.

Introduction

By 2020, 40 percent of the U.S. population will be senior citizens; many will be unable to drive. In fact, one-fourth of today’s 75+ age group does not drive. Moreover, between 2010 and 2030, it is estimated that the “baby-boomer” cohort (65+ years) will grow four times faster than the population as a whole in those two decades (U.S. Bureau of the Census 2008). Seniors “who can confidently use public transportation to get to their appointments, shopping destinations, and to visit friends will be able to live in their own homes much longer than those who are reliant on others for their transportation needs ” (Ammon 2005).
Meeting the transportation needs of seniors is a major community objective as well as a national goal. Public transportation and related travel options represent a lifeline for seniors, linking them with family, friends, and a changing society. To accommodate the growing senior population, several cities have created opportunities and approaches to enable this age group to become mobile by using public transportation.

However, tailoring public transportation to meet seniors’ needs has been somewhat challenging for public transit operators, and many are still researching the best methods and services to this end. Some public transit operators are giving seniors incentives to ride public transportation for discounted prices, and a few operators are offering free rides for seniors. Such was the case in the state of Illinois that enacted a Seniors Free Ride Program in 2008. In the six-county Chicago region, the program was funded by an additional 0.25 percent sales tax and, administratively, it was added to the existing reduced fare program. The program allowed persons over the age of 65 to ride the state’s transit systems free, with important repercussions for transit service providers, especially in the Chicago area.

Indeed, one of the main concerns of agencies contemplating fare-free transit programs is the effect on ridership, revenues, and costs. Clearly, careful ex ante evaluations of such impacts are desirable. Occasionally, however, there is a need to evaluate such impacts during the implementation of a fare-free program. In this regard, this paper discusses ridership and revenue impacts of the program on the Chicago area public transit operators based on findings from a study published elsewhere (DiJohn et al. 2010).

Note that the free-fare program in Illinois was modified in 2011 to run as a means-tested program partially because of cost considerations. However, numerous free-fare transit programs are still in operation (Volinski 2012), and many other agencies, for various reasons, may be contemplating including free-fare options in their operations. In this light, the presentation provides details about the methods specifically developed and implemented to quantify the relevant ridership and revenue of such programs adding thereby to the toolkit of transit planners.

**Literature Review**

**Attitudes of Seniors toward Mobility**

In a survey done in 2005 by the American Public Transportation Association (APTA) of people 65 years or older, 98 percent of respondents felt that maintaining their independence is “extremely important,” yet seniors worry about their mobil-
Ridership and Revenue Implications of Free Fares for Seniors in Northeastern Illinois

ity options and being stranded and cut off from family, friends, medical help, community activities, etc. (APTA 2005). When seniors were asked about their mobility options, although they recognized the importance of public transportation in their community, they preferred to drive and felt there was a lack of transportation options within their community.

Surprisingly, the survey found that about 60 percent of seniors would use public transportation services if they were easily available in their neighborhoods, and 83 percent of participants would use public transit if it provided faster access to their lifestyles needs: doctor’s appointments, entertainment, shopping, and visiting with friends and family. Furthermore, 80 percent of the seniors surveyed believed that public transit is easier and more convenient than driving and 82 percent felt it is a better option at night (APTA 2005).

Industry Experiences with Fare Free Programs

There are only three large metropolitan areas that permit seniors to ride free: Philadelphia, Pittsburgh, and Miami. All have experienced similar ridership trends as the Chicago region. In addition, there were numerous, small urban, rural, and paras-transit operations that offer free service (Volinski 2012) but that were not directly comparable with fare-free operations running at the time in the Chicago region.

In August 2007, the Southeastern Pennsylvania Transportation Authority (SEPTA) expanded the “free” travel hours for seniors to 24hrs/day (from 22hrs/day) on SEPTA buses, trolleys, and subway-elevated lines with valid Medicare Card, Railroad Retirement Card, or Transit ID Card. Prior to this change, seniors traveled at discounted fares during weekdays (with regular fares charged from 7 to 8 AM and 4:30 to 5:30 PM) and all day on weekends and holidays.

In Allegheny County, Pennsylvania the Free Transit Program for Senior Citizens (age 65+) is paid for by proceeds from the Pennsylvania lottery and reimburses the Port Authority for all senior rides. Moreover, in Florida, senior citizens 65 years and older or Social Security beneficiaries who are permanent Miami-Dade County residents are eligible to ride transit free with a Golden Passport.

Other medium-size and smaller agencies with senior free-ride programs include Island Transit in Island County, Washington; the Tri-County Metropolitan Transportation District of Portland, Oregon; the King County Metro in Washington; and the CityLink in Coeur d’Alene, Idaho. The most recent list of such programs can be found elsewhere (Volinski 2012).
Elasticity Studies

There have been free-fare demonstrations of fixed-route services, where fares were reduced 100 percent and made free to the general public (not exclusively to seniors, as in this paper), which have resulted in measurable increases in ridership. Denver made off-peak fares free and experienced an increase in total ridership of 36 percent (Doxsey and Spear 1981), and Mercer County, New Jersey, instituted a similar demonstration program and experienced an increase in total ridership of 16 percent (Studenmund and Connor 1982). Austin, Texas, experienced a total ridership increase of 75 percent but adjusted the result attributable to free fares to 10 percent due to the existence of other factors, including increases in service (Perone and Volinski 2003). Perone and Volinski (2003) also reported anticipated increases in total ridership resulting from free fares of approximately 50 percent. A recent survey found ridership increases from 20 to 60 percent “in a matter of just a few months” (Volinski 2012).

Traditional fixed-route transit demand elasticity relies on the “Simpson & Curtin” demand elasticity—shrinkage ratio, to be more accurate—of -0.33, meaning for every 1 percent increase in fare, there will be a corresponding 1/3 percent loss of ridership (McCollom and Pratt 2004). An informative discussion about various elasticity measures for transportation demand is provided elsewhere (Pratt 2000).

The American Public Transportation Association (APTA) has done further analysis of fixed bus demand and developed a range of elasticity from -0.18 to -0.43, depending on peak or off-peak service and size of metropolitan area. This demand elasticity has also been used to predict ridership when fares are reduced. There is no agreement in the industry that the elasticity for fare increases is also valid for fare reductions. However, using this method to predict free fares, a 100 percent decrease in fares would result in an increase in fixed-route ridership between 18 and 43 percent, depending on size of metro area and whether it is peak or off-peak service (APTA 1991).

A later study (Hodge et al. 1994) noted that the reason fare-free programs often result in ridership increases is that there is a substantial psychological impact, at least among riders in smaller communities, when no fare is required. This is because all financial barriers are negated, and the embarrassment of not knowing what the fare is can be avoided, making a fare-free policy much more effective than a simple reduction in fares. The study concluded that smaller communities, especially, are better served by a fare-free policy. In addition, Metaxatos and Dirks (2012) examined the ridership impact of a free-fare policy for ADA complementary paratransit
service in Illinois and found an estimated average increase in annual ADA trips between 121 and 171 percent in the Chicago area.

**Registration Trends**

The Regional Transportation Authority (RTA) in Chicago is responsible for funding, regional planning, and fiscal oversight of all public transportation in the six-county Northeastern Illinois region as provided by three transit operating agencies: the Chicago Transit Authority (CTA), Metra commuter rail (Metra), and Pace suburban bus and paratransit (Pace). When the RTA implemented the Seniors Ride Free (SRF) program starting in October 2008, it created the SRF fare card. Seniors could use existing reduced fare (RF) cards for free rides until April 2009.

Before the April 2009 deadline, eligible riders were counted as registrants in both programs, minus those who had transitioned but whose RF cards had not yet expired. After April 1, 2009, eligible riders were only those registered for the SRF program. The large increases in the numbers of SRF registrants just before the April 2009 deadline when a senior RF card could no longer be used for free rides can be seen in Figure 1. Reduced fare registrations decreased during the SRF program from 252,260 in March 2008 to 175,632 in December 2009. At the same time, SRF registrations increased from under 2,000 in March 2008 to more than 396,000 in December 2009.

![Figure 1. Senior Reduced Fare and Ride Free registrations](image-url)
Service Boards Ridership Trends

On average, the CTA, Metra, and Pace service boards provide more than 52.5 million monthly trips and total ridership experienced an upward trend between January 2007 and December 2009. At the same time, the estimated reduced-fare ridership decreased from 5.5 million to 3.0 million trips (medium-gray color trendline in Figure 2). Moreover, SRF ridership increased sharply during the first few months of the program to 3 million trips by October 2008. Seniors seemed to take fewer free trips during the winter of 2008, but ridership picked up again and peaked at 3.2 million trips in July 2009. By December 2009, SRF ridership had decreased to 2.6 million trips (Figure 2). The implicit assumption in Figure 2 is that the senior reduced-fare ridership prior to March 2008 (light gray trendline) transitioned into senior fare-free ridership after March 2008 (dark gray trendline).

Figure 2. Service board ridership by month

Between March 2008 and December 2009, seniors took a total of 58.4 million free rides on the RTA system. This represents five percent of total ridership. In the same period, Metra estimated about 3.7 percent of total ridership was free trips for seniors. In addition, free rides for seniors provided during the same period represented 5.1 percent of CTA’s ridership and 6.3 percent of Pace’s total ridership.

Short-Term Ridership Impacts of the SRF Program

The short-term ridership impact of the SRF program is the sum of two trends: (a) diversion of senior rides, previously on reduced fare, to free rides, and (b) attraction of new free rides to the SRF program. Prior to March 2008 when the SRF program was enacted, CTA, Metra, and Pace did not register senior riders separately from other reduced fare riders, which included persons with disabilities, military personnel, students, and children. Therefore, to estimate diversion of rides from the
Ridership and Revenue Implications of Free Fares for Seniors in Northeastern Illinois

reduced fare program to the SRF program, the differences in reduced fare rides were computed for each month from before and after the SRF program went into effect, starting from April 2007 and ending in March 2008—the assumption being that seniors who had been paying a reduced fare were no longer doing so and were riding free. These differences provide an estimate of the senior reduced-fare ridership prior to the start of the SRF program in March 2008 (Figure 2). The average of these monthly differences is an estimate of the diverted rides (call this Estimate A).

To estimate the total number of new free rides attracted to the SRF program for the same period, the total monthly SRF ridership was averaged (call this Estimate B). The estimated number of new rides was then computed to be the difference between Estimates A and B.

The following examples illustrate the method above. Consider the reduced-fare senior ridership change for April 2007 and April 2008 (the first full month of the SRF program). The estimated April 2008 ridership (as a percentage of total ridership) was 2.5 percent lower than that in April 2007 (Table 1). In addition, in April 2008, all Service Boards reported 2,200,905 SRF rides representing 4.0 percent of the total ridership (Table 1). As a result, the short-term impact of the SRF program for April 2008 is the 4.0% - 2.5% = 1.5% gain in new free rides (Table 1). The impact for other months is calculated similarly.

Table 1. Service Board Free Rides and Reduced-Fare Rides Diversion

<table>
<thead>
<tr>
<th>Monthly Difference</th>
<th>RF* Rides, Difference from 1 Year Ago</th>
<th>RF Rides, Difference from 1 Year Ago (%)</th>
<th>Free Rides</th>
<th>Free Rides (%)</th>
<th>Difference between Free Rides and RF Rides (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apr-07-08</td>
<td>-814,138</td>
<td>-2.5%</td>
<td>2,200,905</td>
<td>4.0%</td>
<td>1.5%</td>
</tr>
<tr>
<td>May-07-08</td>
<td>-2,033,146</td>
<td>-4.0%</td>
<td>2,589,894</td>
<td>4.6%</td>
<td>0.6%</td>
</tr>
<tr>
<td>Jun-07-08</td>
<td>-1,705,309</td>
<td>-3.6%</td>
<td>2,713,811</td>
<td>4.9%</td>
<td>1.3%</td>
</tr>
<tr>
<td>Jul-07-08</td>
<td>-1,355,133</td>
<td>-3.1%</td>
<td>2,925,219</td>
<td>5.1%</td>
<td>2.0%</td>
</tr>
<tr>
<td>Aug-07-08</td>
<td>-1,681,666</td>
<td>-3.4%</td>
<td>2,963,729</td>
<td>5.3%</td>
<td>1.8%</td>
</tr>
<tr>
<td>Sep-07-08</td>
<td>-1,484,020</td>
<td>-3.5%</td>
<td>2,868,513</td>
<td>5.0%</td>
<td>1.5%</td>
</tr>
<tr>
<td>Oct-07-08</td>
<td>-1,980,104</td>
<td>-3.9%</td>
<td>3,131,494</td>
<td>5.1%</td>
<td>1.3%</td>
</tr>
<tr>
<td>Nov-07-08</td>
<td>-2,526,688</td>
<td>-5.0%</td>
<td>3,124,623</td>
<td>6.1%</td>
<td>1.1%</td>
</tr>
<tr>
<td>Dec-07-08</td>
<td>-2,584,132</td>
<td>-5.8%</td>
<td>3,117,332</td>
<td>6.5%</td>
<td>0.7%</td>
</tr>
<tr>
<td>Jan-08-09</td>
<td>-1,920,024</td>
<td>-3.8%</td>
<td>3,192,162</td>
<td>6.5%</td>
<td>2.7%</td>
</tr>
<tr>
<td>Feb-08-09</td>
<td>-1,831,578</td>
<td>-3.9%</td>
<td>3,386,573</td>
<td>6.9%</td>
<td>3.0%</td>
</tr>
<tr>
<td>Mar-08-09</td>
<td>-860,257</td>
<td>-2.1%</td>
<td>4,033,241</td>
<td>7.5%</td>
<td>5.5%</td>
</tr>
<tr>
<td>Average</td>
<td>-1,731,350</td>
<td>-3.7%</td>
<td>3,020,625</td>
<td>5.6%</td>
<td>1.9%</td>
</tr>
</tbody>
</table>

* Reduced Fare
The average percentage decrease in reduced-fare senior riders between April 2008 and March 2009 from a year earlier was 3.7 percent, or 1,731,350 rides (Table 1). This is the estimated average diversion of senior rides previously on RF to SRF rides (Estimate A effect). During the same period the average percentage increase in free SRF rides was 5.6 percent, or an estimated 3,020,625 rides (Estimate B effect). Therefore, the average percentage gain in new rides was 5.6% - 3.7% = 1.9% (Table 1), or an estimated 1,289,275 rides.

Figure 3 shows the respective ridership results. The ridership impact of the first effect (Estimate A) is shown as bars going downwards (in darker gray), whereas the ridership impact of the second effect (Estimate B) is shown as bars going upwards (in light gray).

It should be noted that ridership is impacted by other factors as well. During the study period, gasoline prices fluctuated significantly and unemployment in the Chicago region increased. These and other factors influence both general ridership and usage by seniors.

Since the inception of the SRF program, many seniors who previously were eligible for a reduced fare but were not registered had signed up for the additional benefit resulting in a rapid increase in ridership compared to the previous reduced fare program. Through March 2009, according to the estimates above, the program had attracted, on average, 1.3 million new free rides per month compared to an average 1.7 million seniors rides per month with previously reduced fares. This represents a
75 percent increase in ridership, which is not to be confused with a potential overall ridership increase, which is more difficult to calculate since people not registered for the RF program’s travel habits were not analyzed.

**Short-Term Revenue Impact of the SRF Program**

Ideally, one would like to measure the financial implications of the SRF program by comparing two identical systems, one with and one without such a program. Unfortunately, this was not practical to do. This paper also does not discuss the impacts following the program modification in 2011. However, we can assess the revenue loss to the RTA by estimating the revenue that could have been collected if everyone riding free at the time were to pay a fare. This is done in the section below entitled “A Survey Free Approach.”

There are several difficulties with such an approach. One is that it does not take into account additional rides seniors take because rides had become free. One way to incorporate this into our analysis was to compare the present with the situation before the program went into effect. This is not entirely fair since the impact of decreasing fares might not be negative (or the reciprocal of increasing fares). Still, that analysis is possible and is presented below for the SRF program. An advantage of using information from the survey is that it enables incorporation of holders of SRF cards or RF cards who actually use them. A disadvantage of any survey-based approach is just that—it is based on a survey, with all attendant biases, such as non-response bias and recall bias.

The survey-free approach is discussed first because it is probably simpler to implement and demonstrates the feasibility of the evaluation method if survey data are not available. Later, two survey-based approaches are discussed using slightly different assumptions and provide flexibility for the analyst in the presence of available survey data.

**A Survey-Free Approach**

If everyone riding free at the time were to pay a fare, a question arises as to what fare—full fare or a reduced fare? Using two different fares—the average reduced-fare revenue on the low end and the full base fare on the high end—we can compute a range of revenue losses. Since seniors typically pay a reduced fare, one might conjecture that the actual revenue loss would be closer to the lower end of the range.
Average full cash (reduced-fare) fares were computed by dividing the total number of rides paying full cash fare (reduced fare) into the total revenue collected. The weighted average reduced-fare revenue per ride is based on actual usage as computed by each service board. Fare and ridership information was obtained from each service board.

The 2009 annual revenue loss for the SRF program is estimated to be between $26.1 million (based on average reduced-fare revenue loss) and $76.8 million (based on full-cash-fare revenue loss) with a median value (based on the weighted average reduced-fare revenue per ride above) of $38.5 million (Table 2).

Table 2. Estimated Range of Revenue Loss of SRF Program, 2009

<table>
<thead>
<tr>
<th>Service Board</th>
<th>Average Reduced Fare Revenue Loss</th>
<th>Estimated Weighted Average Fare Revenue Loss</th>
<th>Full Cash Fare Revenue Loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>CTA</td>
<td>$18,084,520</td>
<td>$26,817,744</td>
<td>$63,479,205</td>
</tr>
<tr>
<td>Metra</td>
<td>$6,738,920</td>
<td>$9,939,907</td>
<td>$10,007,296</td>
</tr>
<tr>
<td>Pace</td>
<td>$1,269,840</td>
<td>$1,725,566</td>
<td>$3,316,745</td>
</tr>
<tr>
<td>Total</td>
<td>$26,093,280</td>
<td>$38,483,217</td>
<td>$76,803,246</td>
</tr>
</tbody>
</table>

A Survey-Based Approach

A survey of registered seniors was undertaken to identify the habits of free ride users and determine whether they had changed their public transit usage because they were paying no fare. It is generally understood that shorter time frames for recalling events and experiences produces more valid information (Stone et al. 2000). Our experience with the survey of seniors seems to corroborate this observation. As a result, survey-based analysis was as reliable as the recall ability of the seniors responded.

In this light, we discuss two methods for estimating the revenue loss of the SRF program based on a survey of SRF cardholders. Both methods provide a means to estimate the revenue loss one week before and one week after the SRF Program started. This estimate, when considered on an annual basis, can then be compared to the figures estimated by the previous “survey-free” approach.

Sampling Issues

The population of registered SRF cardholders was sampled by area of residence: City of Chicago, the rest of Cook County, and collar counties (DuPage, Kane, Lake, McHenry, and Will). Initially, two options were available: (a) sample in proportion
to the number of seniors in each area or (b) sample in proportion to the number of seniors with senior free cards in each area. The second way seemed to be preferable because the target population was the seniors with SRF cards. Indeed, seniors with an RTA Senior Ride Free card are, in general, proportionally fewer in the collar counties (Table 3). This is not surprising, given the lower availability of transit in the collar counties. Had we ignored this fact and sampled in proportion to the number of all seniors in each area, we would have obtained a very different sample. The mail-out-mail-back survey was to a random sample of 5,000 seniors in July 2009 and achieved an overall return rate of 39.3 percent.

Table 3. Senior Population in RTA Region

<table>
<thead>
<tr>
<th>County</th>
<th>Population Age 65+*</th>
<th>Seniors with SRF Card**</th>
<th>Total Population</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number</td>
<td>Percent</td>
<td>Number</td>
</tr>
<tr>
<td>Cook</td>
<td>624,187</td>
<td>11.79%</td>
<td>213,808</td>
</tr>
<tr>
<td>DuPage</td>
<td>100,835</td>
<td>10.84%</td>
<td>61,737</td>
</tr>
<tr>
<td>Kane</td>
<td>43,543</td>
<td>8.58%</td>
<td>18,596</td>
</tr>
<tr>
<td>Lake</td>
<td>68,863</td>
<td>9.67%</td>
<td>46,953</td>
</tr>
<tr>
<td>McHenry</td>
<td>32,125</td>
<td>10.08%</td>
<td>19,644</td>
</tr>
<tr>
<td>Will</td>
<td>57,505</td>
<td>8.44%</td>
<td>19,993</td>
</tr>
<tr>
<td>Total</td>
<td>927,058</td>
<td>10.98%</td>
<td>380,731</td>
</tr>
</tbody>
</table>


**Data from RTA.

Highlights of Survey Results

The following results pertain to transit use: (a) 44 percent of the respondents did not have a reduced fare card prior to the SRF program; (b) 34 percent of the respondents at the time of the survey used transit one or more times per week; (c) 28 percent responded that they ride transit more frequently as a result of the program; (d) an approximately equal percentage (31%) reported they use cars and taxis less.

In regard to why and how they ride: (a) 13 percent reported taking rides that are work related while 16 percent were employed; (b) 47 percent reported having ridden CTA bus in the week prior to the survey, 25 percent CTA rail, 31 percent Metra, and 17 percent Pace; (c) 50 percent of respondents reported taking more transit trips during rush hour, and 52 percent rode more during weekends since the SRF
program started. These findings are in general agreement with two recent surveys of seniors in the Chicago area (Mohammadian et al. 2009; Mueller and Jane 2007). The socioeconomic profile of the respondents included the following: (a) more than 90 percent were living in households of 1 or 2 people; (b) 79 percent had a driver’s license, and 81 percent had an auto available; (c) 16 percent were employed at the time of the survey, 5 percent less than at the start of the SRF program; (d) 33 percent had incomes less than $22,000 annually; (e) 28 percent had income more than $55,000 annually; (f) 44 percent of the respondents (taking 59 percent of the rides) would qualify for free rides based only on income eligibility (vis-à-vis seniority).

Finally, 71 percent of respondents thought the SRF program should be continued, whereas 24 percent thought it should be limited to low-income seniors; the remaining 4 percent thought the SRF program should be discontinued. However, seniors living in less affluent households in the city, who are frequent riders and live alone or with somebody else, have a markedly more positive attitude toward the SRF program compared to those living in more affluent households in the suburbs, who are infrequent riders and live in larger families.

**Estimating Revenue Loss Using the Deflation Difference Method**

The Deflation Difference method computes the difference in revenue generated by riders between a typical week before March 17, 2008, the starting date of the SRF program (the “before” period) and a week in the first half of June 2009 (the “after” period). The number of rides in the “before” period was estimated as the difference between the number of rides in the “after” period and the additional number of rides seniors reported taking since the SRF program started.

In addition, in the absence of actual usage by seniors of RF and SRF cards, qualitative information from survey responses regarding frequency of card use was quantified as follows:

- Seniors using an RF or SRF card “None of the time” would pay the full fare all the time.
- Seniors using an SRF card “About a quarter of the time” would pay the full fare about 75% of the time and ride free about 25% of the time.
- Seniors using an RF card “About a quarter of the time” would pay the full fare about 75% of the time and half fare about 25% of the time; this is equivalent to paying the full fare about 87.5% of the time.
• Seniors using an SRF card “About half the time” would pay the full fare about 50% of the time and ride free about 50% of the time.

• Seniors using an RF card “About half the time” would pay the full fare about 50% of the time and half fare about 50% of the time; this is equivalent to paying the full fare about 75% of the time.

• Seniors using an SRF card “More than half the time” would pay the full fare about 25% of the time and ride free about 75% of the time.

• Seniors using an RF card “More than half the time” would pay the full fare about 25% of the time and half fare about 75% of the time; this is equivalent to paying the full fare about 62.5% of the time.

• Seniors using an SRF card “All the time” would pay the full fare none of the time (ride free all the time).

• Seniors using an RF card “All the time” would pay the half fare all the time; this is equivalent to paying the full fare 50% none of the time.

It should be noted that without knowing the exact riding behavior of seniors (for example, by comparing the RF and SRF card use of the same riders before and after the SRF program started), we could not assign more specific values to qualitative responses such as “about a quarter of the time,” “about half the time,” or “more than half the time.”

All but the fare information was obtained from the survey of SRF cardholders. The fare information was made available by each service board and is the same information used in other survey-free approaches discussed earlier in this paper. The discussion below provides the mathematical definitions and expressions for the necessary computations.

Let $i$ and $j$ index, respectively, the frequency of use of RF cards (in the “before” period) and SRF cards (in the “after” period). Let $x_{ij}$ be the number of rides in each of the $(i,j)$ categories taken by SRF cardholders in the “after” period who also had an RF card in the “before” period. The total number of rides, $x_{+j}$, for this group, at each level $j$ of SRF card use, is $x_{+j} = \sum_i x_{ij}$. Similarly, the total number of rides, $x_{i+}$, at each level of SRF card use $j$ for RF cardholders who now use a SRF card is $x_{i+} = \sum_j x_{ij}$.

In the “after” period, there were also a number of rides taken by SRF cardholders who did not have an RF card in the “before” period. Let’s call the number of rides at
each level $j$ of SRF card use for this group $x_j^{(no\ RF)}$. Clearly, the total number of rides taken by SRF cardholders in the “after” period is $x_{++} = \sum_j x_{+j} + x_j^{(no\ RF)}$.

Let $z_{ij}$ be the number of additional rides in each of the $(i, j)$ categories taken by SRF cardholders in the “after” period who also had an RF card in the “before” period. The total number of rides for this group at each level $j$ of SRF card use is $z_{+j} = \sum_i z_{ij}$. Similarly, the total number of additional rides at each level $j$ of SRF card use for RF cardholders who now use a SRF card is $z_{ij} = \sum_j z_{ij}$.

In the “after” period, there were also a number of additional rides taken by SRF cardholders who did not have an RF card in the “before” period. Let’s call the number of rides at each level $j$ of SRF card use for this group $z_j^{(no\ RF)}$. Clearly, the total number of additional rides taken by SRF cardholders in the “after” period is $z_{++} = \sum_j z_{+j} + z_j^{(no\ RF)}$.

An estimate of the number of rides in the “before” period can be obtained by taking the difference of $x_{ij}$’s and $z_{ij}$’s. More specifically, the total number of rides taken by RF cardholders at each level $j$ of RF card use in the “before” period is $y_{+j} = x_{+j} - z_{+j}$.

In the “before” period, there were also a number of rides taken by seniors who did not have an RF card. Note that these rides would not appear separately in the service boards ridership (reduced-fare or SRF) counts. An estimate of the total number of rides taken by seniors who did not have an RF card in the “before” period is $y_{+}^{(no\ RF)} = \sum_j x_{+j}^{(no\ RF)} - z_{+j}^{(no\ RF)}$.

Let $u_i$ and $v_j$ be the portion of full fare for a particular level $i$ of RF card use, and level $j$ of SRF card use, respectively. Let $u_i = u_i \times (2008 \text{ fare})$ and $v_j = v_j \times (2009 \text{ fare})$ be, respectively, the quantities $u_i$ and $v_j$ after absorbing fare information in the “before” and “after” periods.

The computation of the above quantities is done for each service board with specific ridership and fare profiles. Let’s now discuss the revenue generated in the “before” and “after” periods.

Following the discussion above, the total revenue per week generated by SRF riders in the “after” period is $R_{after} = \sum_j [x_{+j} + x_j^{(no\ RF)}] \times v_j$. Similarly, the total revenue per week generated by RF riders in the “before” period is $R_{before} = \sum_i (y_{+i} \times u_i) + y_{+}^{(no\ RF)} \times (2008 \text{ fare})$. This is because seniors in the “before” period without an RF card would be paying the full 2008 fare.

The total revenue loss per week for each service board is then simply $R = R_{before} - R_{after}$. Using this method, the total revenue loss estimate of the SRF program was
estimated to be $34.4 million per year, $4.1 million less than the median estimated loss of the survey free approach discussed earlier (Table 4).

**Table 4. Deflation Difference Method vs. Survey-Free Approaches**

<table>
<thead>
<tr>
<th>Service Board</th>
<th>Revenue Loss Using Deflation Difference Method</th>
<th>Revenue Loss Using Average Reduced Fare</th>
<th>Revenue Loss Using Average Full Cash Fare</th>
<th>Estimated Weighted Average Fare</th>
</tr>
</thead>
<tbody>
<tr>
<td>CTA</td>
<td>$30,794,970</td>
<td>$18,084,520</td>
<td>$63,479,205</td>
<td>$26,817,744</td>
</tr>
<tr>
<td>Metra</td>
<td>$1,612,289</td>
<td>$6,738,920</td>
<td>$10,007,296</td>
<td>$9,939,907</td>
</tr>
<tr>
<td>Pace</td>
<td>$1,944,686</td>
<td>$1,269,840</td>
<td>$3,316,745</td>
<td>$1,725,566</td>
</tr>
<tr>
<td>Total</td>
<td>$34,351,945</td>
<td>$26,093,280</td>
<td>$76,803,246</td>
<td>$38,483,217</td>
</tr>
</tbody>
</table>

**Estimating Revenue Loss Using the Deflation Ratio Method**

The Deflation Ratio method operates on the entire table of SRF rides taken by seniors with and without a prior RF card, not just at the margins. If this were the only difference, the two methods would give identical results. A second difference between the two methods is that the “before” period ridership (obtained by taking the difference between SRF rides and additional SRF rides as discussed in the Deflation Difference method) is not used directly into the revenue loss calculation; it is rather used to compute “deflation factors” of the SRF ridership, as explained below.

Let $d_{ij} = \frac{y_{ij}}{x_{ij}}$, the ratio of SRF ridership ($x_{ij}$) and RF ridership ($y_{ij}$) be the deflation factor of SRF ridership for a particular ($i,j$) category of RF and SRF card use. Recall that the weekly RF ridership can only be indirectly estimated as the difference between the weekly SRF ridership and the additional number of SRF rides in that same week. As a result, whenever the number of additional rides reported is greater than SRF ridership because of recall issues, the deflation factor is set equal to 1—the SRF ridership in each category of card use would logically be larger than the RF ridership given that the SRF Program has attracted additional rides. The deflation factor is also set equal to 1 in cases where particular ($i,j$) categories are absent. A missing value analysis could have rendered less arbitrary values for those few cases. Available methods for this problem are discussed elsewhere (Brownstone 1998; Wang and Shao 2003; Cox 2002; Metaxatos 2009).

Let also $p_{ij} = \frac{x_{ij}}{x_{++}}$ be the percentage of all SRF rides, $x_{++} = \Sigma \Sigma x_{ij}$, in each ($i,j$) category. Following the notation in the previous section, the total revenue loss per week (for each service board) is:
\[ R = R^{(\text{before})} - R^{(\text{after})} = \]
\[ \sum_{i} \sum_{j} y_{ij} u_{i}^{x_{ij}} - x_{ij} v_{j}^{x_{ij}} = \sum_{i} \sum_{j} d_{ij} x_{ij} u_{i}^{x_{ij}} - x_{ij} v_{j}^{x_{ij}} = \sum_{i} \sum_{j} d_{ij} x_{ij} u_{i}^{x_{ij}} - x_{ij} v_{j}^{x_{ij}} \]
\[ = \sum_{i} \sum_{j} d_{ij} p_{ij} x_{ij} u_{i}^{x_{ij}} - p_{ij} x_{ij} v_{j}^{x_{ij}} = \sum_{i} \sum_{j} p_{ij} (d_{ij} u_{i}^{x_{ij}} - v_{j}^{x_{ij}}) x_{ij} \]

where,

\[ \begin{align*}
  i_{1} &= \text{None of the time} \\
  i_{2} &= \text{About a quarter of the time} \\
  i_{3} &= \text{About half the time} \\
  i_{4} &= \text{More than half the time} \\
  i_{5} &= \text{All the time} \\
  i_{6} &= \text{No RF card before SRF program} \\
  j_{1} &= \text{None of the time} \\
  j_{2} &= \text{About a quarter of the time} \\
  j_{3} &= \text{About half the time} \\
  j_{4} &= \text{More than half the time} \\
  j_{5} &= \text{All the time} 
\end{align*} \]

The following three examples will illustrate the method. In the first example, let’s assume that 0.2% of the rides were taken by seniors who had but did not use a reduced fare card or a SRF card. Therefore, the weekly revenue loss for this category would be:

\[ 0.2\% \times [100\% \times (\text{full fare}) \times (\text{weekly RF ridership}) - 100\% \times (\text{full fare}) \times (\text{weekly SRF ridership})] = \]
\[ [0.2\% \times (\text{full fare}) \times (100\% \times (\text{weekly RF ridership}) - [100\% \times (\text{weekly SRF ridership})] = \]
\[ 0.2\% \times [(\text{deflation factor}) \times 100\% - 100\%] \times (\text{weekly SRF ridership}) \times (\text{full fare}) \]

In a second example, let’s assume that 0.02% of the rides were taken by seniors who had but did not use an RF card, and use a SRF card (approximately) 25% of the time. Therefore, the weekly revenue loss for this category would be:

\[ 0.02\% \times [100\% \times (\text{full fare}) \times (\text{weekly RF ridership}) - 75\% \times (\text{full fare}) \times (\text{weekly SRF ridership})] = \]
\[ 0.02\% \times (\text{full fare}) \times [(100\% \times (\text{weekly RF ridership}) - 75\% \times (\text{weekly SRF ridership})] = \]
\[ 0.02\% \times [(\text{deflation factor}) \times 100\% - 75\%] \times (\text{weekly SRF ridership}) \times (\text{full fare}) \]
In the third example, let’s assume that 0.24% of the rides were taken by seniors who used an RF card (approximately) 25% of the time and never use a SRF card. Therefore, the weekly revenue loss for this category would be:

\[
0.24\% \times \left\{ \left[ \left( 25\% \times \text{half fare} \right) + \left( 75\% \times \text{full fare} \right) \right] \times \text{(weekly RF ridership)} \right. \\
\left. - \left[ 100\% \times \text{full fare} \times \text{(weekly SRF ridership)} \right] \right\} = \\
0.24\% \times \text{(full fare)} \times \left[ \left( 87.5\% \times \text{(weekly RF ridership)} \right) - \left( 100\% \times 2009 \text{ SRF ridership} \right) \right] = \\
0.02\% \times \left[ \left( \text{deflation factor} \times 87.5\% - 100\% \right) \times \text{(weekly SRF ridership)} \times \text{(full fare)} \right]
\]

Using the same ridership and fare information for each service board as above, the Deflation Ratio method estimates the total annual revenue loss of the SRF program to be $34.9 million, about $0.5 million more than the deflation difference method and about $4.6 million less than the previous survey free approach (Table 5).

**Table 5. Deflation Ratio Method vs. Survey-Free Approaches**

<table>
<thead>
<tr>
<th>Service Board</th>
<th>Deflation Ratio Method</th>
<th>Average Reduced Fare</th>
<th>Average Full Cash Fare</th>
<th>Estimated Weighted Average Fare</th>
</tr>
</thead>
<tbody>
<tr>
<td>CTA</td>
<td>$26,880,499</td>
<td>$18,084,520</td>
<td>$63,479,205</td>
<td>$26,817,744</td>
</tr>
<tr>
<td>Metra</td>
<td>$6,589,925</td>
<td>$6,738,920</td>
<td>$10,007,296</td>
<td>$9,939,907</td>
</tr>
<tr>
<td>Pace</td>
<td>$1,466,571</td>
<td>$1,269,840</td>
<td>$3,316,745</td>
<td>$1,725,566</td>
</tr>
<tr>
<td>Total</td>
<td>$34,936,995</td>
<td>$26,093,280</td>
<td>$76,803,246</td>
<td>$38,483,217</td>
</tr>
</tbody>
</table>

**Discussion of the Results from the Survey-Free and Survey-Based Methods**

The results obtained using the deflation difference and the deflation ratio methods should not be too far apart. The former method operates on the margins of the table of SRF rides taken by seniors with and without a prior RF card, while the latter operates on the entire table. Overall, recall issues with survey respondents affect the deflation factor method more than the deflation difference method (generally speaking, ratios magnify between-periods fluctuations more than differences).

In the particular application discussed in this paper, seniors in 7 out of 25 categories of frequency of SRF and RF card use for Metra reported having made more RF rides than SRF rides. Note that only one such category for Pace and none for CTA exhibit the same phenomenon. An additional issue with the deflation ratio method is that a few of the categories above are absent: three for CTA, four for Metra, and seven for Pace.
An advantage of using the deflation ratio method vis-à-vis the deflation difference method is that it allows using SRF ridership from different sources. For example, we could have used the actual SRF ridership (obtained from the service boards) increased by a survey-based estimate of rides taken by seniors without their SRF card (these rides would not have been recorded separately as senior rides). In any case, both survey-based methods estimate a total revenue loss closer to the one estimated by a survey-free method based on a weighted average fare. Therefore, the total revenue loss can be reasonably estimated to range between $34.3 and $38.4 million.

Conclusions
The magnitude of the short-term financial loss for the SRF program raises questions about the financially sustainability of the program, especially considering the demographic projections of the regional senior population. In fact, under conservative scenarios, the SRF program would have doubled its revenue losses by 2030 (DiJohn et al. 2010). Indeed, Illinois legislators may have been thinking along these lines when they decided to roll back the SRF program and make it available only as a means-tested program starting in September 2011. The methods discussed, however, provide the tools for relevant ridership and revenue impact evaluations of existing and future free-fare transit programs.

It should be noted, however, that the estimated revenue loss reported in this paper will not directly translate into revenue gains. This is because it is reasonable to assume (based on the survey information) that after the revision of the SRF program about 60 percent of the senior rides would be free based on income eligibility. The potential “gain” would be further deflated under the assumption that some seniors would simply stop riding because it would no longer be free.

Nevertheless, this paper discussed several approaches to evaluate the ridership and revenue impact of a policy decision such as the one that, at least temporarily, allowed seniors to ride public transportation for free in Illinois. In an era of very tight budgets among transit operators, it has become more critical than ever to assess the implications of such policies, preferably before implementation. However, when there is a need to conduct such an assessment during a fare-free program implementation, the methods proposed in this paper would add to the toolbox that transit planners use and eventually contribute to improving the understanding of similar policy decisions.
Acknowledgments

This paper was made possible by the support of the Metropolitan Transportation Support Initiative in the Urban Transportation Center of the University of Illinois at Chicago. We would also like to acknowledge the assistance from RTA, CTA, Metra, and Pace in providing all data necessary to complete the analysis.

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