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- Main Body - organized under section headings
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Intermodal Connectivity to BRT: A Comparative Analysis of Bogotá and Curitiba

Fábio Duarte, Pontifícia Universidade Católica do Paraná
Fernando Rojas, Pontificia Universidad Javeriana, Bogotá

Abstract

Bogotá and Curitiba have become important references for public transportation in Latin America and have gained worldwide recognition for their technically and managerially innovative bus-based public transportation systems (Bus Rapid Transit, BRT). However, despite the huge success of these projects, most people living in these cities still use other modes for their daily trips. The main aim of this paper is to investigate whether, and how, these cities adopt a multimodal approach when planning and implementing their innovative BRT projects. We compare how pedestrians, cyclists, and taxi and car users are linked to the BRT system in each of these cities and conclude that minor changes in both systems could improve their multimodality.

Introduction

Bogotá and Curitiba have become important references for public transportation in Latin America and have gained worldwide recognition, both in the technical and scientific literature, for their technically and managerially innovative bus-based public transportation systems. Technical manuals, such as those published by Embarq (2010) or ITDP (2007), depict Bogotá and Curitiba as reference models for public transportation because of the Bus Rapid Transit (BRT) networks successfully implemented in these cities. The World Bank even considers that BRT “can enable
new categories of passengers, including more women and children, to benefit from an improved level of safe, accessible, and reliable public transport” (Rickert 2010, p. 1). BRT is also considered an important element of a greenhouse gas reduction policy (Wright and Fulton 2005).

BRT has undoubtedly improved the quality of public transportation in several Latin American cities, from Santiago de Chile to Caracas. Also in Latin America, Curitiba and Bogotá are examples of best practices. However, the success of a public transportation project should not be based on a single major mode. In some cities in developed countries, BRT has been chosen over LRT (light rail transit), mainly for economic reasons, such as in Ottawa in the late 1970s (Rathwell and Schijns 2002), or to complement more robust rail systems, such as the Metro in Shanghai and Beijing (Xu 2004). In developing countries, BRT has been implemented as the main, if not only, mass transportation system, examples being South Africa (Cape Town) and Asia (Jakarta). Most of the developing countries have experienced an increase in the number of private vehicles per capita, reaching an annual increase of 10 percent (UN-Habitat, 2010), or vehicle sales increasing over 50 percent per year in China (Sperling and Claussen 2004, p. 11); but non-motorized modes are still relevant, even for important metropolises in developing world, reaching 33 percent in Delhi and Bangalore, 53 percent in Beijing (LTA Academy 2011), 33 percent in São Paulo (Metrô 2007), and 37 percent in Rio de Janeiro (Rio de Janeiro 2004). Common forms of public transportation include vans, minibuses, and taxis.

The same scientific journals that highlight the merits of BRT frequently publish papers that point out the importance of a multimodal approach in meeting contemporary mobility challenges, such as the need to achieve socioeconomic equilibrium or reduce environmental impacts associated with urban transportation. Vincent and Jerram (2006, p. 222) even calculate “that it is likely that a BRT system can achieve significantly greater CO\textsubscript{2} reductions than LRT” in American cities, both because the electricity used to power LRT comes from fossil fuels and because the cost of building an LRT is significantly higher than the corresponding cost for a BRT. The implication of the latter is that because more BRT than LRT can be built for the same dollar amount, which will translate into greater CO\textsubscript{2} emissions.

The main aim of this paper is to investigate whether, and how, Bogotá and Curitiba adopt a multimodal approach when planning and implementing their innovative BRT projects. A comparison is made of how pedestrians, cyclists, and taxi and car users are linked to the BRT system in each of these cities. Then, based on this, some brief recommendations are presented for improving urban mobility in these cities,
demonstrating that the combination of different modes can enhance an urban mobility network and may improve the overall quality of trips for its users.

**BRT in Curitiba and Bogotá: An Overview**

**Curitiba, a Pioneer**

Curitiba is considered one of the first cities to have implemented a BRT system. It pioneered BRT in Latin America and has been a key inspiration for other cities on the continent, including Bogotá (Duarte Carvajal 2009; Ardila 2004).

The first BRT line in Curitiba was planned at the end of the 1960s and launched in 1974, when the city had 609,000 inhabitants. However, at the time, it was not considered a BRT. In fact, what has become known as the Curitiba BRT has its origins in a series of sociotechnical struggles spanning 40 years: every time the bus system was challenged, mainly because it had insufficient capacity to move a growing population, a rail project was presented as the solution; and every time such a project was presented, the necessary financial support was not available and the rail project was abandoned (Duarte et al. 2001). Nevertheless, as Duarte et al. (2011) have shown, some of the innovations associated with the Curitiba BRT are the result of these failed rail projects.

This sociotechnical relationship between rail and bus started in 1969, before the first bus corridor was implemented. The most recent development in this relationship involves a new metro project for the city, which was approved in 2008. Again, this is based on the same argument as previous rail projects (Duarte et al. 2011): that the BRT network is reaching its maximum capacity, moving more than 2.2 million passengers daily from a population of 1.7 million in Curitiba and more 1.3 million in the metropolitan area.

The main characteristics of Curitiba's BRT that can be traced back to failed rail projects include bus platforms at the same level as the floor of the bus; speedy boarding and alighting; prepaid fares; automated fare collection; greater spacing between bus stops (from 500 m up to 3 km); and integration of trunk and feeder lines in main stations. These characteristics are now seen as the basic framework of a full BRT.

The BRT extends over 72 kilometers and runs along what are known as the North-South, East-West, and Boqueirão corridors, as shown in Figure 1. A new 18 kilometer corridor, called the Green Line, is under construction, transforming a former
federal highway in a metropolitan axis, a central BRT corridor, and restricted freight traffic. The fleet at the time of writing consists of 1,915 buses, of which 60 run on biofuels and 185 run in segregated corridors (Lindau et al. 2010; Hagen 2009).¹

![Source: Urbs](image)

**Figure 1. High density along the North-South BRT corridor in Curitiba**

All public transportation in Curitiba is part of the RIT (Integrated Transport Network) (Figure 2), which also provides partial coverage in neighboring cities. It is run by URBS, a 99.9% publicly-owned company, whose president is appointed by the mayor of Curitiba.

**Bogotá, Revamping BRT**

Bogotá implemented its BRT system at the end of the 1990s. A private company called Transporte del Tercer Milenio Transmilenio S.A., was created to plan and operate the new system. Since then, its name has become synonymous with the whole system (Gómez 2003). When the BRT system was implemented, the city was experiencing marked growth in private transportation, and public transportation was very disorganized, operated by a myriad of small and micro bus companies with more than 20,000 buses and minibuses. Average vehicle speed was between 12 km/h and 18 km/h (Gómez 2003).
Figure 2. Integrated Transport Network of Curituba
The first corridor came into operation in 2000. From the beginning, the system was planned to be a full BRT network, and the original plan foresaw 388 km of corridors and 4,500 buses, at a cost of US$5 million per kilometer (Duarte Carvajal 2009). At the time of writing, two of the network’s eight phases have been completed, and a third is under construction, corresponding to a total of 84 kilometers of segregated bus corridors, in which 1,290 articulated and bi-articulated buses circulate.

An innovation introduced by Bogotá in the BRT concept is that in addition to regular lines, which stop at every bus stop, there are express lines, which stop only at the main stations, thus increasing the overall operating speed of the system (Rojas et al. 2004), as shown in Figure 3. Curitiba has recently introduced an adapted form of this solution, introducing a bypass lane in some segments of a corridor that is used by an express line that stops only at the terminals and main stations.

![Figure 3. Transmilenio corridor, Avenida 1, in Bogotá](image)

The main lines, which are operated with bi-articulated buses, are fed at the terminals, or portales, by feeder lines from the metropolitan area. The next step is to integrate local lines, which are currently operated by small private companies that provide a poor-quality service and compete for passengers by bargaining for fares on the road, the so-called “cents war,” as each driver tries to attract more passengers by reducing his fare, regardless of comfort, operating speed, reliability, or safety.

*A Brief Comparison of the Two Cities*

Table 1 shows a comparison of BRT in Bogotá and Curitiba.
Table 1. Comparison of BRT in Bogotá and Curitiba

<table>
<thead>
<tr>
<th></th>
<th>Bogotá</th>
<th>Curitiba</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population (city)</td>
<td>7,304,384</td>
<td>1,751,907</td>
</tr>
<tr>
<td>Number of lines</td>
<td>8 (1)</td>
<td>8 (1)</td>
</tr>
<tr>
<td>Total length of BRT corridors (km)</td>
<td>84</td>
<td>72</td>
</tr>
<tr>
<td>Passengers per day</td>
<td>1,660,000 (2)</td>
<td>2,260,000 (3)</td>
</tr>
<tr>
<td>PKI (passenger-kilometer index)</td>
<td>5.1</td>
<td>2</td>
</tr>
<tr>
<td>Fare</td>
<td>US 0.90</td>
<td>US 1.5</td>
</tr>
<tr>
<td>Number of terminals</td>
<td>13</td>
<td>22</td>
</tr>
</tbody>
</table>

(1) Feeder lines are not included; (2) only passengers on the BRT corridors are included; (3) passengers in the full system, including feeder lines.

Sources: Bogota—CCB - Cámara de Comercio de Bogotá, Transmilenio S.A. (October 2011); Embarq (2010). Curitiba—Urbs (taxis and buses, December 2011); DETRAN-PR (private cars and motorcycles, July 2011); IPPUC (bicycle paths, December 2011).

Despite the differences in population and daily number of passengers, both systems have frequently been mentioned together as examples of full BRT systems. Other cities, such as Beijing (Shi et al. 2010) and Sydney (Currie 2006), have implemented what can be called BRT systems only within a very loose conceptual and technical framework.

The BRT systems in Curitiba and Bogotá not only are technically comparable but also face similar challenges, as metro projects are being considered in both cities.

In Bogotá, the planned extension to the system has been delayed, as the system’s ability to meet demand is being questioned both locally and nationally, and funds are increasingly difficult to secure (Caracol 2011; La Republica 2012). A victim of its own success, Transmilenio is crowded and unable to solve the transit problems of a growing city, where it is the subject of strong criticism (Gilbert 2008). Since 2008, a metro project has been in the advanced technical stages of discussion, and construction of a first line, which should already have started, has been delayed by political disagreements between municipal, national, and multilateral bodies. The detailed design is expected to be ready by 2012.

Coincidentally, in 2008, Curitiba approved its new urban mobility plan, in which replacement of one of the BRT lines by a metro is mentioned. In 2010, the environmental impact assessment of the project was completed and approved, and in
2011, the municipality obtained federal funds for implementation of the first 14 km of the metro, to be built under the southern BRT corridor.³

**Outside the BRT network**

The aim in this paper is to investigate whether, and how, other existing modes of transportation are addressed in the context of urban mobility in these cities. To this end, it is worth describing briefly the participation of other modes in daily trips in these cities. Table 2 summarizes the relevant data.

<table>
<thead>
<tr>
<th>Table 2. Comparison of Urban Mobility in Bogotá and Curitiba</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Bogotá</strong></td>
</tr>
<tr>
<td>Population (city)</td>
</tr>
<tr>
<td>Private cars, #</td>
</tr>
<tr>
<td>Price of gasoline (litres)</td>
</tr>
<tr>
<td>Taxis, #</td>
</tr>
<tr>
<td>Flag drop</td>
</tr>
<tr>
<td>Fare per kilometer</td>
</tr>
<tr>
<td>Motorcycles, #</td>
</tr>
<tr>
<td>Bicycles (km of bicycle paths)</td>
</tr>
</tbody>
</table>

Sources: Bogotá—CCB–Cámara de Comercio de Bogotá; Transmilenio S. A (December 2011); Bogotá Transporte (taxis, March 2012). Curitiba—Urbs (taxis, March 2012); DETRAN-PR (private cars and motorcycles, July 2011); IPPUC (bicycle paths, December 2011).

In Bogotá, 58 percent of all daily trips are made by public transportation (10% use Transmilenio), while private cars are responsible for 14 percent, taxis 5 percent, and bicycles and pedestrians 17 percent (CCB 2007). Despite the fact that there are no regular or reliable data on modal share in Curitiba, it is possible that, based on a survey conducted by the National Public Transportation Association (ANTP 2009), buses are responsible for 36 percent of all trips in cities with more than 1 million inhabitants, private cars 28 percent, and bicycles less than 2 percent, while 33 percent of trips are made on foot. These numbers not only show the significant position public transportation occupies in both cities but also indicate that a multimodal approach is important to cater for the majority of the population, particularly members of the poorest segment, who depend on non-motorized modes for their complete journey, or at least a significant part of it. Multimodality is, therefore, essential in these two cities, as it is in several other cities in developing countries where there is even a modern public transportation system in place. BRT systems operate along
main corridors, and other modes are needed to reach these corridors. Hence, it can be seen that a multimodal approach is beneficial for BRT projects.

**BRT and Multimodality**

Passengers can access the BRT system in Bogotá and Curitiba through both bus stops and terminals. However, terminals are a key intermodal element to the BRT systems in both cities because this is where feeder routes connect passengers to other destinations outside the BRT network. For this reason, the terminals were taken as a proxy to analyze how well the BRT system in these two cities is integrated with other modes including bicycles, pedestrians, private automobiles, and taxis.

**Methodology**

In our field research, all the terminals were visited to determine whether they were, or could be, integrated with other means of transportation. For integration with the pedestrian mode, the existence of a crosswalk near the terminal entrances and the condition of the sidewalks within a 100-meter radius of the terminal were considered. To analyze the condition of a sidewalk, its width (a good sidewalk being deemed to have a minimum of 1.2 meters free for pedestrians) and the quality of its surface were checked. The existence of access to the terminal and bus platform for people with disabilities was also checked. For bicycles, the presence of bicycle lanes or bicycle paths leading to the BRT terminal or the vicinity of the terminal were checked, as was whether there was parking for bicycles. For cars, the points checked were whether there were taxi stands and parking for privately-owned cars.

The following form (Figure 4) was used in both cities.

<table>
<thead>
<tr>
<th>TERMINAL: Name</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>PEDESTRIANS</strong></td>
</tr>
<tr>
<td>Crosswalk near entrances?</td>
</tr>
<tr>
<td>Yes</td>
</tr>
<tr>
<td>No</td>
</tr>
<tr>
<td>Condition of sidewalk:</td>
</tr>
<tr>
<td>Segment 1</td>
</tr>
<tr>
<td>No</td>
</tr>
<tr>
<td>Access to terminal?</td>
</tr>
<tr>
<td>No</td>
</tr>
<tr>
<td>Access to the platform?</td>
</tr>
<tr>
<td>Yes</td>
</tr>
<tr>
<td>TAXI</td>
</tr>
<tr>
<td>No</td>
</tr>
<tr>
<td>Yes</td>
</tr>
<tr>
<td>NB:</td>
</tr>
</tbody>
</table>

**Figure 4. Form used to evaluate BRT intermodality**
The situation in Bogotá in terms of multimodality, considering the terminals as transportation nodes, is shown in Table 3.

### Table 3. Analysis of Terminal Multimodality in Bogotá

<table>
<thead>
<tr>
<th>Terminal</th>
<th>Pedestrian access</th>
<th>People with reduced mobility: access to terminal</th>
<th>People with reduced mobility: access to platforms</th>
<th>Taxi</th>
<th>Parking</th>
<th>Bicycle lanes</th>
<th>Bicycle lanes (200 m)</th>
<th>Bicycle parking</th>
</tr>
</thead>
<tbody>
<tr>
<td>Portal Norte</td>
<td>Y</td>
<td>N</td>
<td>Y</td>
<td>N</td>
<td>Y</td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Portal Sur</td>
<td>Y</td>
<td>N</td>
<td>Y</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Portal Americas</td>
<td>Y</td>
<td>N</td>
<td>Y</td>
<td>N</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Portal Suba</td>
<td>Y</td>
<td>N</td>
<td>Y</td>
<td>N</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Portal Usme</td>
<td>Y</td>
<td>N</td>
<td>Y</td>
<td>N</td>
<td>Y</td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Portal 80</td>
<td>Y</td>
<td>N</td>
<td>Y</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Portal Tunal</td>
<td>Y</td>
<td>N</td>
<td>Y</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Calle 40 Sur</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Molinos</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>CR 77 La Granja</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>Av Cali</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>Banderas</td>
<td>Y</td>
<td>N</td>
<td>Y</td>
<td>N</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>General Santander</td>
<td>Y</td>
<td>N</td>
<td>Y</td>
<td>N</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
</tbody>
</table>

All terminals in Bogotá have good pedestrian access, with crosswalks and traffic lights at all entrances. Whenever a BRT corridor is implemented in Bogotá, improvements are made to the roads as well as the sidewalks near the terminals. In contrast, even though all platforms are adapted for people with reduced mobility, access to terminals from the street for these users is nonexistent at all terminals at the ends of routes, and only four of the intermediate terminals have facilities for disabled people. This situation can be seen in Figure 5.
Another aspect of multimodality is the integration of different modes of transportation, including individual modes. While there are no taxi stands directly connected to any terminal. Integration is much better for bicycles: eight out of the thirteen terminals can be reached by bicycle paths. It is interesting that in two of the terminals reached by bicycle paths, there is no parking space for bicycles. The integration with bicycles can be seen in Figure 6.
### Table 4. Analysis of Terminal Multimodality in Curitiba

<table>
<thead>
<tr>
<th>Terminal</th>
<th>Pedestrian access</th>
<th>People with reduced mobility: access to terminal</th>
<th>People with reduced mobility: access to platforms</th>
<th>Taxi</th>
<th>Parking</th>
<th>Bicycle lanes</th>
<th>Bicycle lanes (200 m)</th>
<th>Bicycle parking</th>
</tr>
</thead>
<tbody>
<tr>
<td>Campina do Siqueira</td>
<td>partial</td>
<td>partial</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td>Campo Comprido</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
<td>Y</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Capão Raso</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
<td>N</td>
<td>Y</td>
<td>N</td>
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<tr>
<td>Carmo</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
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<td>Centenário</td>
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<td>Y</td>
<td>Y</td>
<td>N</td>
<td>N</td>
<td>N</td>
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<td>Y</td>
<td>N</td>
<td>Y</td>
<td>N</td>
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<tr>
<td>Fazendinha</td>
<td>Y</td>
<td>Y</td>
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<td>Y</td>
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<td>Y</td>
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<td>Hauer</td>
<td>partial</td>
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<td>Pinhais</td>
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<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
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<td>Bairro Alto</td>
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<td>Y</td>
<td>N</td>
<td>N</td>
<td>Y</td>
<td>N</td>
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</tr>
</tbody>
</table>

Only 55 percent of terminals in Curitiba have pedestrian-friendly access. In some cases, the access was considered to be only partial because of the poor quality of the sidewalks and the absence of disability ramps. Only one terminal is not adapted...
for people with reduced mobility. Nevertheless, while the situation is very good inside the terminals, at 39 percent of people with reduced mobility have difficulties gaining access. This situation can be seen in Figure 7.

Figure 7. Terminal Cabral, Curitiba—sidewalk with good pavement, but without access for people with reduced mobility

Taxis are the alternative transportation mode with the best connection to the BRT system in Curitiba: taxi stands are present in 64 percent of the terminals, as shown in Figure 8. In contrast, private car parks are present at only 20 percent of the terminals.

Figure 8. Terminal Santa Cândida taxi stand

The situation with bicycles is even more critical: only 6 of the 22 terminals have a bicycle path adjacent to them. This figure rises to 10, however, if terminals with a
bicycle path no more than 200 meters away are included. Nonetheless, and underlining the extent to which bicycles are ignored as a complementary transportation mode, bicycle parking is available in only 2 of the 22 terminals.

**Conclusions**

Although the BRT systems in Bogotá and Curitiba have become international references, some local critics suggest that they have reached their maximum capacity. Mass rail systems are been designed for both cities. However, we believe that cities in developing countries require a multimodal approach, as cars, taxis, bicycles, and pedestrians are responsible for a huge number of daily trips in both cities. And despite the impressive 58 percent of the trips in Bogotá made by public transport, this figure does not include trips made before reaching a BRT station (which are normally on foot but may also be by bicycle), as these are not counted in modal share surveys. Multimodality is, thus, a fact of life. It is against this background that this research has tried to analyze whether, and in what way, multimodality is part of the BRT systems in Bogotá and Curitiba.

Bogotá has good pedestrian access, and 8 out of 13 terminals can be easily and safely reached by bicycle; in contrast, private cars and taxis are not considered modes that could complement the system. Similarly, in Curitiba, although most of the terminals have taxi stands, 20 percent of the terminals have car parks, indicating that they could be considered as a complementary mode. Only 6 out of the 22 terminals can be easily and safely reached by bicycle, and only 2 have bicycle parking, which is not integrated with the terminal. Half of the terminals have poor pedestrian access, and the sidewalks in the vicinity are in poor condition.

These findings are especially important if one considers that public transportation and non-motorized transportation are the only options for the poor. In Bogotá, for instance, the lowest socioeconomic strata (i.e., the poorest members of society) are responsible for 97 percent of all bicycle trips, travelling around 10 kilometers a day (Massink 2009).

Challenged by a powerful modes like a metro, which has greater capacity and a better image among the public, the BRT systems in Bogotá and Curitiba need to improve in a number of ways. Some of these relate to the BRT systems themselves and include the delivery of technical improvements by emulating metro and LRT services and the development of a positive image among the public (Hess and Bitterman 2008). However, there is still scope for both cities to improve and modern-
ize their BRT systems by enhancing their interaction with other modes. Pedestrians and cyclists are obviously the main target because they are users of non-motorized modes.

In November 2011, Bogotá inaugurated a public bicycle-sharing program called BiciBog, the pilot project of which operated near Transmilienio stations so that bicycles could feed into the BRT system. Likewise, Curitiba plans to issue an invitation to tender for a Bicycle Plan in 2012. With regard to taxis and private cars, improved intermodality with these forms of transport offers several advantages. First, by providing taxi stands and car parks, park-and-ride schemes can be stimulated. Second, as the number of cars increases and the shortage of parking spaces in cities central areas in particular becomes more acute, new car parks could provide BRT operators with a source of revenue that could be reinvested in the BRT system.

This paper has endeavored to show that the multimodality that is important for daily trips in both Bogotá and Curitiba is not currently part of these successful BRT systems but could become part of them.

Endnotes


3 See the official website at http://www.metro.curitiba.pr.gov.br.

Acknowledgments

The authors would like to thank Wesley Medeiros (PUCPR, Curitiba) and Juan Manuel Restrepo (PUJ, Bogota), both undergraduate students, for their help. This research was partially funded by the Brazilian National Council for Research (CNPq) and Fundação Araucária.

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Evaluating and Enhancing the Operational Performance of Public Bus Systems Using GIS-based Data Envelopment Analysis

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Abstract

In this paper, the baseline performance level of Al Ain Public Bus Service is evaluated using Data Envelopment Analysis (DEA) based on some selected input (travel time per round trip, total number of stops, total number of operators, total number of buses) and output (daily ridership and vehicle-kilometer) variables. Two types of scenarios were developed and tested. The first set of scenarios aimed at investigating the possibility of reducing the operating cost while maintaining the same performance levels (efficiency and effectiveness) for the routes. The second set of scenarios was used to demonstrate how the baseline performance levels can be improved by slightly altering the route alignment (and subsequently input and output variables). Sensitivity analysis was then conducted to measure the efficiency and effectiveness of each route. Conclusions on how the transit authority can reduce daily operating hours while maintaining the existing performance level are made. Also, suggestions are presented on how to improve the overall performance level of the bus service by changing some route characteristics.
Introduction

Public transit systems are essential parts of the modern urban life. In some countries such as the United Arab Emirates (UAE), where such mode of transport is relatively new and people can easily avail private vehicles, it is quite essential to operate public bus service efficiently and effectively to make this mode choice more favorable to private vehicles.

Public bus services should operate efficiently and effectively, from both demand and supply perspectives. Although the general terminologies of “efficiency” and “effectiveness” may seem to be closely related, these two measures are required to be considered separately in public transit system (Hatry 1980; Chu et al. 1992). As for effectiveness, people should feel that buses are available to meet their daily travel demand with lower cost. As such, effectiveness can be measured by service utilization (ridership), service quality, and accessibility to the service (Fielding et al. 1985). As for efficiency, the service authority typically aims at minimizing the operational cost without hampering the daily travel demand of the people. As such, efficiency measures describe the relationship between resource inputs and produced output and includes indicators of overall cost efficiency, labor utilization, and vehicle utilization (Fielding et al. 1985). Both efficiency and effectiveness were used as measures within the DEA context. In fact, much of the reported literature has used the two measure types to evaluate transit system performance within the DEA context (Chu et al. 1992; Karlaftis 2004; Lao and Liu 2009).

It is important to seek optimum solutions to operation parameters (e.g., schedules, frequencies) without jeopardizing the necessities of operation (meeting demands while achieving the highest levels of customer satisfaction). Balancing both sides of demand and supply issues is not an easy task and usually entails reduction of service quality to attain more reasonable levels of expenditures. That is, minimizing operation and maintenance costs (input) usually comes at the expense of a reduction in ridership. Similarly, maximizing throughput (ridership) is usually associated with higher operational cost.

Commonly, the goal of transit system authorities is to provide as much efficient and effective service to users regardless of the operating costs (Chu et al. 1992; Karlaftis 2004), especially during the first few years of operation until the systems are mature enough and are well reputed to attract traditionally private car users. This is commonly coupled with continuous assessment of performance, and even setting benchmarks and to improve service (Park and Kamp 2004). In economics, performance assessment or efficiency are measured by comparing levels of output.
to input (Cooper et al. 2004; Fare et al. 1994; Nash 2006; Barnum et al. 2007). The assessment normally starts with identifying the important operation characteristics (inputs) and the targeted outputs. In public transit systems, multiple outputs are produced by multiple inputs (Barnum et al. 2007), and it is difficult to aggregate all input and output variables into a single scale to measure the performance levels. Data Envelopment Analysis (DEA) provides an innovative approach to resolve such difficulties to measure the relative efficiency of the system (Barnum et al. 2007).

This paper aims at developing and presenting an approach using the DEA method that can be used to investigate the operational characteristics of service, identify drawbacks in operation through GIS-based data analysis, and provide a framework that can be adopted to mitigate such deficiencies in a cost effective manner. The approach is demonstrated through the newly-introduced bus service in Al Ain in the UAE.

This paper builds upon earlier data collection for the study of evaluating public bus services in Abu Dhabi and Al Ain in the UAE (RTTSRC 2010). The paper describes the data collection methodology and the obtained results aiming at evaluating the performance of Al Ain public bus service from an operational perspective. This entails analyzing the field data of all bus routes in Al Ain. Two types of scenarios were developed and tested. The first set of scenarios aims at investigating the possibility of reducing operating cost while maintaining the same performance levels (efficiency and effectiveness) for the routes. The second set of scenarios was used to demonstrate how the baseline performance levels can be improved by slightly altering the route alignment (and subsequently input and output variables). Sensitivity analysis was then conducted to measure the efficiency and effectiveness of each route.

**Literature Review**

A number of studies were conducted to identify the key performance indicators of public transit services based on the goals and objectives of the authorities (Tomazinis 1977; Gilbert and Dajani 1975; Fielding et al. 1978; Meyer and Gomez-Ibanez 1981; Forkenbrock and Dueker 1979; Bly and Oldfield 1986; Cervero 1984). These studies used relatively variant performance indicators. As such, these studies cannot be used to reach a generalized conclusion (Benjamin and Obeng 1990; Karlaftis 2004). This has led some researchers to conclude that it may be necessary to use
a more concise yet reliable set of indicators to describe the public transit system performance (Karlaftis 2004).

Anderson and Fielding (1982) and Fielding et al. (1985), in an effort to reduce the number of indicators, used factor analysis to reduce 48 performance indicators to 7 measures. Benn (1995) selected a number of inputs and categorized these into five broad groups to determine the evaluation standards: route design, schedule design, economics and productivity, service delivery and monitoring, and passenger comfort and safety. The study concluded that service quality and operating cost were the most two important factors for the users to evaluate the overall service effectiveness.

In general, in transit systems, labor, capital and energy are used as inputs, while efficiency measures such as vehicle kilometers, seat kilometers, or passenger kilometers are used as outputs (Fielding et al. 1985; De Borger et al. 2002). Karlaftis (2004) further defined each of these input levels using quantitative measures. For example, the labor input factor is defined as the total number of employees (including operators, maintenance staff, and administrative personnel). Capital is defined as the total number of vehicles operated by the system. Energy is defined as the total annual amount of fuel used by the system (in gallons). Vehicle-miles and passenger-miles were used as the output variables to measure the efficiency and effectiveness of U.S. transit systems. Sanchez (2009) and Sakano et al. (1997) used the number of full-time workers, fuel consumption, and number of operating buses as the input variables.

Sanchez (2009) used a number of output variables such as vehicle kilometers, seating capacity, service hours, number of passengers, and average age of the fleets to evaluate bus service performance of Spanish transport systems. Lao and Liu (2009) evaluated the performance of bus lines from the operational and spatial aspects. Operating time, round-trip distance, and number of stops were used as inputs to measure operational efficiency. Total number of bus users, population age 65+ years, and number of persons with disabilities using the service were used as the inputs to measure spatial effectiveness. In both cases, total annual number of passengers was used as the output.

There are two approaches to assess the performance of the transit system: either by comparing to standards or by measuring and assessing the relative efficiencies if no standards are available. As there are no standards available to benchmark service in the UAE, the second approach was chosen to assess bus service performance. There are several methods to measure and assess performance. The methods can
be classified as parametric and non-parametric tests. Pucher (1982) used correlation coefficients to measure performance. Karlaftis et al. (1997) applied a t-test technique to measure whether there was a significant change in the performance of transit system of two models. Boschken (2000) and Obeng and Azam (1995) used the ordinary least square methods (OLS) to calculate the production and cost functions, respectively. All of these are parametric techniques to measure the performance of a transit system.

These parametric techniques entail assumptions on the functional forms of the production or cost functions. This motivated researchers to use non-parametric approaches that entail fewer assumptions (Sanchez 2009). The non-parametric technique known as Data Envelopment Analysis (DEA) has been widely used to measure the efficiencies and effectiveness of public transit systems (Zhu 2003). DEA was used in many studies to evaluate the public transit service performance (Cowie and Asenova 1999; Pina and Torres 2001; Kersten 1999; Odeck and Alkadi 2001; Boil’e 2001 and Nakanishi and Norworsworthy 2000). Chu et al. (1992) developed a single index for measuring service efficiency as well as service effectiveness of public transit agencies using DEA. Barnum et al. (2008) evaluated the performances of 46 bus routes of U.S. transit systems using the DEA method.

DEA is a non-parametric approach and linear programming technique to measure relative efficiencies of a set of peer units called Decision Making Units (DMUs). This is based on the original work of Farrel (1957) and was later popularized by Charnes et al. (1978) as the CCR model. The CCR model is fairly inflexible in the sense that it assumes constant returns to scale in its production possibility set (Karlaftis 2004). Later, Banker et al. (1984) developed an efficiency frontier structured by both constant and decrease returns to scale. The underlying assumption is that each DMU requires certain resources or inputs to produce its goods or services (outputs). It is used to empirically measure productive efficiency of DMUs by comparing it to the best practice of a DMU or combination of DMUs (Lao and Liu 2009). This model is called the BCC model.

**DEA Model**

DEA is a linear programming-based technique for measuring the relative performance of organizational units where the presence of multiple inputs and outputs makes comparisons difficult. Such organizational units are referred to as DMUs. In this work, DMU is the term used to refer to bus routes. Extensive literature and tuto-
rials on DEA can be found in Emrouznejad (2001). DEA models can be classified based on their orientation into two types: input- and output-oriented models. The input-oriented models minimize the inputs while producing at least the observed output levels. The output-oriented models improve the performance of a DMU by maximizing its outputs, while consuming at most the observed input levels (Forsund 2001).

The type of model orientation to use depends on the objective of the decision maker. If the objective is to minimize the cost of service, the input-oriented DEA model is chosen. On the other hand, if the objective is to maximize the output level, the output-oriented model is chosen. In this study, the output-oriented BCC model was chosen to maximize ridership (number of passengers). In the UAE, the public transit system was recently introduced with the objective of offering services regardless of operational cost. Another reason to choose the BCC model is that it employs a Variable Return to Scale (VRS) assumption, which means that efficiency may increase or decrease with a change in size in input or output. Mathematically, VRS suggests that the estimated production frontier can pass anywhere relative to the origin in input-output space (Lao and Liu 2009).

Mathematically, the BCC model (Banker et al. 1984) can be written as follows:

\[
\begin{align*}
\text{Max}_{u,v} \quad & \quad \theta_k = \frac{\sum_{m=1}^{M} u_m y_{mk}}{\sum_{n=1}^{N} v_n x_{nk}} \\
\text{subject to} \quad & \quad \sum_{m=1}^{M} u_m y_{mj} \leq 1 \quad \forall j \\
& \quad \sum_{n=1}^{N} v_n x_{nj} \\
& \quad \sum_{n=1}^{N} v_n x_{nk} = 1 \\
& \quad u_m, v_n, y_{mj}, x_{nj} > 0 \quad \forall m, n, j
\end{align*}
\]

Where,

- \( j \): Index of decision making unit (DMU), \( j=1,...,J \)
- \( n \): Index of input, \( n=1,...,N \)
- \( m \): Index of output, \( m=1,...,M \)
- \( x_{nj} \): The \( n^{th} \) input for the \( j^{th} \) DMU
- \( y_{mj} \): The \( m^{th} \) output for the \( j^{th} \) DMU
\( um, vn \): Non-negative scalars (weights) for the \( m \)th output and the \( n \)th input

\( \theta_k \): Efficiency/Effectiveness ratio of DMU\(_k\)

The targeted DMU (of a given evaluation) is designated as DMU\(_k\). The BCC model (Eq. 1) maximizes the ratio of weighted outputs to the weighted inputs. The weights \( u_m \) and \( v_n \) are the decision variables. These weights are changed until the ratio (of the weighted outputs to the weighted inputs) is maximized for the target DMU\(_k\), while same weights are applied to all DMUs. The value of the ratio, \( \theta \), in (1) is referred to as the efficiency/effectiveness score of DMU\(_k\), where \( 0 \leq \theta \leq 1 \). For a fully efficient DMU, the value of \( \theta \) is 1. It is to be noted that the weights are the decision variables and that the values of inputs and outputs are the actual observed values. Constraint (3) ensures the DEA model's Variable Returns to Scale (VRS). Constraint (4) imposes non-negativity restrictions for the weights.

**Al Ain Bus Services**

Public bus service has been operated in the UAE for more than a decade. The Department of Transport (DOT) in the Emirate of Abu Dhabi conducted major upgrades to the service (new routes, buses, etc.) in Al Ain around 2009 and 2010. Currently, there are eight routes operating in the city. Figure 1 illustrates the paths of the eight inter-city bus routes in Al Ain. This paper uses the GPS-based collected data to illustrate how the DEA model, combined with a GIS analysis technique, can be used to enhance the operational efficiency of the bus routes.

![Figure 1. Paths of the inter-city bus routes in Al Ain city](image_url)
Methodology

Data Collection and Analyses
Extensive surveys were carried out on all eight routes for three different peak periods (7–9 AM, 12–2 PM, and 5 to 9 PM) daily, over a one-week duration. Three types of surveys were used: a user opinion survey, an operator survey, and a log survey (RTTSRC 2010). Only the log survey data were used in this paper to measure the performance level of the Al Ain bus service. In this survey, the locations of all bus stops (latitude and longitude data) were collected using GPS devices. The numbers of passengers boarding/alighting at each bus stop were counted manually and inserted into the same log survey form.

The collected data were used to estimate the total number of stops on each route direction and their exact locations, route lengths, average number of passengers per day on each route, travel time of each trip for all routes, operating hours, total number of buses operated on each route, total number of operators working on each route, user’s concerns about each route, etc.

Selection of Input and Output Variables for the DEA Model
As previously indicated, labor, capital and energy measures are the most commonly-used inputs in literature. On the other hand, vehicle kilometers, seat kilometers, or passenger kilometers are the most commonly-used outputs (De Borger et al. 2002). Because of the absence of the actual cost data for labor, fuel, and other operational expenses, many researches have used different input variable sets to represent the cost variables (Karlaftis 2004; Lao and Liu 2009). Based on the types of input and output variables, three approaches were identified in the literature to use DEA to measure the efficiency and effectiveness of a transit system. The approaches are 1) separate sets of input and output variables (Chu et al. 1992); 2) separate input but same output variables (Lao and Liu 2009); and 3) same input but separate output variables (Karlaftis 2004).

As an example for the separate inputs separate outputs approach, Chu et al. (1992) used annual vehicle operating time, annual maintenance expenses, annual administrative expenses, and annual other expenses as input variables and annual revenue vehicle hours as the output variable to measure efficiency. They used urbanized area population density, proportion of households with automobile, annual revenue vehicle hours, and annual financial assistance per passenger as the input variables and annual unlinked passenger trips as the output variable to measure effectiveness.
As an example of separate inputs and same output approach, Lao and Liu (2009) used operation time, round-trip distance, and number of bus stops as the input variables for measuring operational efficiency. They used number of commuters using buses, population age 65+, and persons with disabilities as the input variables for effectiveness measurement. They used number of total passengers as the output variable for measuring both efficiency and effectiveness of the transit system.

As an example of same input but separate output variables, Karlaftis (2004) used total number of employees, total annual amount of fuel used by the system, and total number of vehicles as the input variables to measure both efficiency and effectiveness. The output variables of vehicle-miles and ridership were used to measure the efficiency and effectiveness, respectively.

Due to the unavailability of detailed cost and population data, the third approach was followed in this study. Earlier studies indicated that cost of operating a bus route is related to four specific measures: number of stops (Lao and Liu 2009), number of operators, number of operating buses (Sanchez 2009), and average travel time. As the objective of the study was to measure the relative performance of the bus routes, these four variables were selected as the input variables representing the broad cost category for the DEA model proposed in this paper. For example, number of operators is an implicit representation of labor cost; number of operating buses is an implicit representation of capital cost, and number of stops together with average travel time will both implicitly represent fuel cost.

The output of a transit system can be quantified using vehicle-kilometers and/or passenger boarding (Karlaftis 2004). The vehicle-kilometers variable is related to the service produced or efficiency. Passenger boarding is more related to the consumption of services; more passengers indicates more utilization, more consumption of service, or better effectiveness. Therefore, vehicles-kilometers and passenger boarding or ridership data were selected as output variables to measure transit service efficiency and effectiveness, respectively (Karlaftis 2004; Fielding 1987). The four mentioned input variables were used to measure both efficiency and effectiveness of the Al Ain transit system.

All field data were prepared in the form of round-trip data per day to provide consistency. The DEA model used in this study has four input and two output variables, as shown in Table 1. The DEA model in this case has eight DMUs (routes). It is to be noted that some data were extracted from DOT records: total number of trips per day on each route, number of vehicles operating on each route, and number of operators. Other variables such as total travel length and travel time for
each round trip, total number of stops, and average daily passengers were obtained from the field survey data. Table 1 shows the selected inputs and output variables of the baseline (current) operating conditions (for the DEA model).

### Table 1. Input and Output Variables of Baseline (Current) Operating Conditions (for DEA Model)

<table>
<thead>
<tr>
<th>Route # (DMUs)</th>
<th>Input Variables</th>
<th>Output Variable</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average travel time per round trip (hr)</td>
<td>Total # of passengers per day (effectiveness measure)</td>
</tr>
<tr>
<td></td>
<td># of vehicles</td>
<td># of operators</td>
</tr>
<tr>
<td>900</td>
<td>2.43</td>
<td>6</td>
</tr>
<tr>
<td>930</td>
<td>3.20</td>
<td>8</td>
</tr>
<tr>
<td>940</td>
<td>2.78</td>
<td>6</td>
</tr>
<tr>
<td>950</td>
<td>2.72</td>
<td>6</td>
</tr>
<tr>
<td>960</td>
<td>2.45</td>
<td>6</td>
</tr>
<tr>
<td>970</td>
<td>3.10</td>
<td>8</td>
</tr>
<tr>
<td>980</td>
<td>3.26</td>
<td>8</td>
</tr>
<tr>
<td>990</td>
<td>3.85</td>
<td>10</td>
</tr>
</tbody>
</table>

DEA is used to measure the efficiency of a system, given the inputs that represent the cost items or operational characteristics and the outputs of the system. If the output variable(s) reflects the efficiency measure (such as vehicle-kilometers per day), then the DEA is actually evaluating the “efficiency” of the bus system. If the output reflects the effectiveness measure (total number of passengers per day), then the DEA is actually evaluating the “effectiveness” of a system. That is, the DEA method is used herein to measure:

1. Effectiveness or cost-effectiveness: total number of passengers per day on each route is the output variable used as the measure for effectiveness—the measure to be maximized.

2. Efficiency or produced service efficiency: vehicle-kilometers per day on each route is the output variable used as the measure for efficiency.

Detailed analyses were conducted on the minimum number of variables to be included. Initially, the analysis was conducted with seven input variables. More input variables will likely reveal that all routes are effective (or efficient). On the other hand, only a few input variables are likely to result in wrong conclusions on the effective (or efficient) routes, as the system cost is represented by only a few variables and ignoring important cost items. By trial and error, the authors con-
cluded that the used four input variables are the minimum essential ones to be included.

Each of these inputs is used to reflect one of the cost items. Number of vehicles on each route implicitly reflects the capital cost. Number of operators implicitly reflects operators cost. Average travel time and number of stops are intended to implicitly capture on the operational or fuel consumption cost.

**Efficiency and Effectiveness Score of Baseline Condition**

The efficiency and effectiveness measures were estimated using a readily-available Microsoft EXCEL macro (Productivity Tools 2005), which uses the same set of equations (Eqs. 1–4) to calculate the efficiency and effectiveness scores. The vehicle-kilometers and total average number of passenger per day were used as the output variables to measure the efficiency and effectiveness of the transit system, respectively. A scale to classify the efficiency and effectiveness scores was used, according to Lao and Liu (2009):

There is empirical evidence to indicate a linear relationship between the inputs and output variable. Carrying out a linear regression analysis between the efficiency measure “vehicle kilometers per day on each route” and the input variables reveals significant linear relationship with an R2 value of 0.98, and a significant F-value of about 135. This justifies the use of the DEA approach as a linear programming approach.

An efficiency and effectiveness score ($\theta$) equal to 1 means an efficient and effective system. An efficiency and effectiveness score ($\theta$) between 0.6 and 1 means a fairly efficient and fairly effective system. An efficiency and effectiveness score ($\theta$) of less than 0.6 means and inefficient and ineffective system. Tables 2 and 3 show the efficiency and effectiveness scores, respectively. The DMUs efficiency and effectiveness scores are classified according to the scale by Lao and Liu (2009).

**Table 2. Efficiency Scores of Each Route for Baseline Condition**

<table>
<thead>
<tr>
<th>DMUs</th>
<th>Efficiency scores</th>
<th>Return-to-scale</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>900</td>
<td>1.00</td>
<td>Increasing</td>
<td>Efficient</td>
</tr>
<tr>
<td>930</td>
<td>0.99</td>
<td>Decreasing</td>
<td>Fairly Efficient</td>
</tr>
<tr>
<td>940</td>
<td>0.80</td>
<td>Increasing</td>
<td>Fairly Efficient</td>
</tr>
<tr>
<td>950</td>
<td>0.83</td>
<td>Increasing</td>
<td>Fairly Efficient</td>
</tr>
<tr>
<td>960</td>
<td>1.00</td>
<td>Constant</td>
<td>Efficient</td>
</tr>
<tr>
<td>970</td>
<td>1.00</td>
<td>Constant</td>
<td>Efficient</td>
</tr>
<tr>
<td>980</td>
<td>0.72</td>
<td>Decreasing</td>
<td>Fairly Efficient</td>
</tr>
<tr>
<td>990</td>
<td>1.00</td>
<td>Decreasing</td>
<td>Efficient</td>
</tr>
</tbody>
</table>
Table 3. Cost-Effectiveness Scores of Each Route for Baseline Condition

<table>
<thead>
<tr>
<th>DMUs</th>
<th>Cost-effectiveness Scores</th>
<th>Return-to-scale</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>900</td>
<td>1.00</td>
<td>Increasing</td>
<td>Effective</td>
</tr>
<tr>
<td>930</td>
<td>0.84</td>
<td>Decreasing</td>
<td>Fairly Effective</td>
</tr>
<tr>
<td>940</td>
<td>1.00</td>
<td>Constant</td>
<td>Effective</td>
</tr>
<tr>
<td>950</td>
<td>0.54</td>
<td>Increasing</td>
<td>Ineffective</td>
</tr>
<tr>
<td>960</td>
<td>1.00</td>
<td>Increasing</td>
<td>Effective</td>
</tr>
<tr>
<td>970</td>
<td>0.56</td>
<td>Decreasing</td>
<td>Ineffective</td>
</tr>
<tr>
<td>980</td>
<td>1.00</td>
<td>Constant</td>
<td>Effective</td>
</tr>
<tr>
<td>990</td>
<td>0.88</td>
<td>Decreasing</td>
<td>Fairly Effective</td>
</tr>
</tbody>
</table>

Table 4. Classification of Al Ain Bus Routes According to Efficiency and Effectiveness Scores

<table>
<thead>
<tr>
<th></th>
<th>Effective</th>
<th>Fairly Effective</th>
<th>Ineffective</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Efficient</strong></td>
<td>900</td>
<td>990</td>
<td>970</td>
</tr>
<tr>
<td><strong>Fairly efficient</strong></td>
<td>940</td>
<td>930</td>
<td>950</td>
</tr>
<tr>
<td><strong>Inefficient</strong></td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Based on the scales of the efficiency and effectiveness scores, Table 4 provides a summary in the form of a classification matrix for all routes.

It can be observed from the Table 4 that routes 900 and 960 are the most effective and efficient ones. One of the reasons for such high performance may be that these two routes have average demand levels as compared to other routes, but their input variables are the least among the others. As such, the DEA has identified these to be among the most effective routes.

No route is performing inefficiently in Al Ain, but routes 950 and 970 are performing ineffectively. This may be due to the relatively low passenger demands on these routes. The long distance (the geographical extension) that these two routes serve may be another reason for the low number of daily passengers. Route 950 operates between the Bawadi Mall (a major production/attraction commercial zone surrounded by low-income labor accommodation areas) and Al Towaya districts (a relatively high-income residential zone, where the majority of residents prefer to travel via their own private vehicles). In brief, one could argue that one route end is a major production/attraction zone while the other is not. This results in relatively low demands of bus passengers along this route.
The 950 route can be envisioned to have two parts. The first part (from Bawadi to the city center) is the one highly used, and the second part (from the city center to Towaya) is not effectively used. The first part is mostly used by captive riders (low-income class), as the origin is close to their residence. The second part is mostly used also by captive riders because of the frequent stops that discourage high-income choice riders using the service. Also, with the destination being a high-income residential zone, the demand on this part of the route is relatively small. Enhancing the service on the second part of the route by providing express service to the destination can help attract more choice riders.

Route 970 operates between the Al Bateen East district (a residential zone in the far suburban area of the city) and the Mubazzara district (a tourism and recreational area with very few or no residential accommodations). This may also explain the relatively low passenger demands along this route.

It can be said that the original alignment of these routes did not pay particular attention to the nature of the origin/destination zones. The original alignment of the city bus routes was determined to provide nearly full spatial coverage of the entire city, but not necessarily based on the expectations of the bus passenger demands from/to the various zones. This is evident in the long travel time per round trip (some round trips amount for more than three hours) and the extremely high number of stops (some routes serve more than 100 bus stops), as shown in Table 1.

**Experimental Scenarios**

Two types of experimental scenarios were developed and tested. The first set of scenarios aimed at investigating the possibility of reducing operating cost while maintaining the same performance levels (efficiency and effectiveness) for the routes. The second set of scenarios aimed at demonstrating how the baseline performance levels can be improved by slightly altering the route alignment (and, subsequently, the input and output variables). The details of these two sets of scenarios are explained in more detail below.

**Scenarios for assessing the impact of operating cost reduction**

Routes 980, 930, and 950 were selected (from the “fairly efficient” group) for further analysis. The three routes exhibit various levels of effectiveness (“effective,” “fairly effective,” and “ineffective,” respectively). Different scenarios were intuitively suggested and developed for further analysis. The objective was to check whether lowering the operating cost may affect the performance level significantly. The
actual operating cost data were not readily available in monetary value. As such, herein, it is assumed that operating cost is related to the hours of operation. That is, operational cost (increase or decrease) will be affected by a change in operating hours. If, for instance, operating hours are reduced by 20 percent from the current operating hours (18.5 hours daily), operational cost will be reduced by the same percentage. Herein, the term “operating hours” refers to the total number of hours for which bus service is provided.

Three separate scenarios were considered here to reduce operating cost. Scenario 1 entails reducing the operating hours on route 980 by discontinuing the service during times where the passenger loading (in any hour) is less than a specific threshold (defined here as 5 passengers per hour). Scenarios 2 and 3 entail reducing the operating hours on routes 930 and 950, respectively, by discontinuing the service (operation hours) based on the defined threshold. In addition to these individual scenarios, combined scenarios were also considered—for instance, combining scenarios 1 and 2, 2 and 3, etc.

In deciding the trips to be discontinued, the hours that have very little impact on service attractiveness were selected. These hours were specified as those in which very few passengers use the service. The idea here was to eliminate round trips with very few passengers, which will subsequently reduce operating cost and have very little impact on service attractiveness to passengers.

It was found that for 3 hours 25 minutes of overall operating hours (1 round trip for the 980 route), the number of passengers was less than or equal to 5. Eliminating this round trip on the 980 route schedule reduces the overall vehicle-km per day. Herein, we assumed that the total number of passengers per day reduced by the number of passengers using the bus service eliminated a round trip. Similarly, it was found that a total of 5 hours 15 minutes (2 round trips) and 5 hours 30 minutes (2 round trips) can be discontinued for routes 930 and 950, respectively.

It was assumed that the changes on one route affect the characteristics and, as such, the performance measures of that route. For example, discontinuing some round trips on route 980 (scenario 1: reducing overall operating hours by 3 hours 25 minutes) affects vehicle-kilometers as well as total daily passengers and, as such, the performance measures (efficiency and effectiveness) of the route. The effect of changing the characteristics of the route (reducing its operating times) may or may not spread to other route performance measures, as will be explained later.

The modified values of the output variables for the three individual scenarios are shown in Table 5. It is to be noted that the values of the input variables for these
Operational Performance of Public Bus Systems Using GIS-based Data Envelopment Analysis

Scenarios are the same as the base condition. The total number of round trips made by each of these three routes (930, 950 and 980) is 36 per day. Reduction percentages have been calculated based on the number of round trips per day. It was assumed that reducing 1 round trip for route 980 will reduce 2.7 percent of the total operating cost per day for this route.

Table 5. Modified Values of Input and Output Variables for All Scenarios

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Route # (DMUs)</th>
<th>Input variables</th>
<th>Output variables</th>
<th>Percentage of reduction in operating cost</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Avg. travel time per round trip (hr)</td>
<td># of vehicles</td>
<td># of operators</td>
</tr>
<tr>
<td>1</td>
<td>980</td>
<td>3.26</td>
<td>8</td>
<td>20</td>
</tr>
<tr>
<td>2</td>
<td>930</td>
<td>3.2</td>
<td>8</td>
<td>20</td>
</tr>
<tr>
<td>3</td>
<td>950</td>
<td>2.72</td>
<td>6</td>
<td>15</td>
</tr>
</tbody>
</table>

Scenario for improving the performance level

Strategies to enhance the performance levels of the routes could entail changing route schedules, alignment, frequencies, etc. For the impact of these strategies to be quantified, transit planning tools are commonly used in some sort of “what if” type of studies. Such planning tools are commonly limited by internal assumptions that determine how passenger demand patterns are influenced by these strategies. The validity of such assumptions and the planning parameters represent limitations to argue the validity of these models’ results. In this paper, we demonstrate how the DEA model can be used to assess the strategies meant to improve the performance levels.

The performance matrix (Table 4) shows that routes 930 and 950 are the least performing routes. These two routes were selected for further analysis to improve their performance levels.

In general, the public bus routes of Al Ain can be characterized by their excessively long route lengths, ranging between 56 and 102 kilometers per round trip (as measured through the GIS technique). The number of stops or the average travel time per round trip is associated with this route length, i.e., higher travel time or higher number of stops for a longer route length. Furthermore, the number of passengers may not be evenly distributed along the whole route. For example, for route 950, more passengers board to go to the town center from the Bawadi Mall area compared to from the Towaya area (Figure 2). The strategy to enhance the performance
of these two routes (930 and 950) entails splitting them into four routes (930A, 930B, 950A, 950B). The underlying rationale for developing such a split route scenario is that the long route length might hamper the overall performance level of the transit system.

Figure 2 illustrates the paths of the new split routes. The four new routes coincide with the Al Ain central area. The number of passengers along these new routes was calculated based on the number of passengers boarding/alighting at each bus stop. The route length and corresponding number of stops and average number of passengers per day for these split routes were calculated using a GIS tool. The values of other input variables were split according to the split length ratio of the two initial routes (930 and 950). The vehicle-kilometers (per day) were then calculated. The values of the input and output variables of these split routes are shown in Table 6. It is to be noted that the values of the input and output variables for the other routes were kept as in the base condition.

![Figure 2. Paths of the split routes](image)
Table 6. Modified Values of Input and Output Variables for Split Routes

<table>
<thead>
<tr>
<th>Route # (DMUs)</th>
<th>Avg. travel time per round trip (hr)</th>
<th># of vehicles</th>
<th># of operators</th>
<th>Total # of stops (round trip)</th>
<th>Total avg. # of passengers per day</th>
<th>Vehicle-km (per day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>930A</td>
<td>1.8</td>
<td>5</td>
<td>11</td>
<td>69</td>
<td>1,476</td>
<td>1,872</td>
</tr>
<tr>
<td>930B</td>
<td>1.4</td>
<td>3</td>
<td>9</td>
<td>59</td>
<td>2,214</td>
<td>1,476</td>
</tr>
<tr>
<td>950A</td>
<td>1.45</td>
<td>3</td>
<td>8</td>
<td>72</td>
<td>1,039</td>
<td>1,152</td>
</tr>
<tr>
<td>950B</td>
<td>1.25</td>
<td>3</td>
<td>8</td>
<td>58</td>
<td>1,039</td>
<td>972</td>
</tr>
</tbody>
</table>

Results and Analyses

Results and analysis of operating cost reduction scenarios

The DEA model was run again to recalculate the efficiency the effectiveness measures of the individual routes as a result of the above service changes (scenarios). Figure 3 exhibits the efficiency scores for all considered scenarios. As can be seen, routes 930, 950, and 980 exhibit changes in efficiency scores. The efficiency scores of all the other routes remain fixed.

Similarly, Figure 4 illustrates the effectiveness scores of all the routes as a result of all tested scenarios. Figures 3 and 4 clearly illustrate that very little change occurred to the efficiency and effectiveness scores as a result of the service changes. That is, the operating cost could be reduced as a result of the service hour changes while maintaining the same levels of efficiency and effectiveness.

The efficiency and effectiveness classifications remain the same (exactly as in Table 4), similar to the classification of the base condition. Figure 5 shows the deviation of efficiency scores for all scenarios from the base condition. The positive deviation means the efficiency score of the scenarios is lesser than that of the base condition. The maximum deviation (0.054) was encountered for route 930.

The reduction in the service operating hours had a slight effect on the efficiency measure. The reason is that the changes or reductions made in operating hours were not accompanied by significant changes to vehicle-kilometers or number of passengers. The combined scenario (1, 2, and 3) is the preferred one, as this will reduce the operating hours for all three routes.
Figure 3. Efficiency scores of all scenarios for different routes

Figure 4. Effectiveness scores of all scenarios for different routes
Figure 5. Deviation of efficiency scores of different scenarios for all routes

Figure 6 shows the deviation of effectiveness scores for all combinations of scenarios. It should be observed that the proposed changes to the service on routes 930, 950, and 980 (reducing the operating hours) have a slight impact on other routes’ effectiveness. For example, routes 930, 970, and 990 are performing more effectively under some scenarios and less effectively under others. The effectiveness of route 980 was not affected by any of the scenarios. The effectiveness score is a relative term (as compared to other routes [DMUs]). As such, changing the input or output variables of one route may influence other routes’ effectiveness measures.

The reason for the changes in routes 930, 970 and 990 is that their reference or peer DMUs have greater influence on their performance level. That is, the output results of this DEA model indicate that the effectiveness score of route 970 is influenced by its reference or peer DMUs (namely, routes 940 and 980) with the proportions of 33.67 and 66.34 percent, respectively. On the other hand, the efficiency score of route 970 is not influenced by any other route (the efficiency score of route 970 is 1). This explains why scenario 1 (entailing changes to route 980) has affected the effectiveness score of route 970 and has not affected its efficiency scores.
It is evident from Figure 6 that scenario 1 results in the best effectiveness measures. However, it is to be noted that the other scenarios, although negatively affecting the effectiveness measures, may still be attractive scenarios, as they result in reduction of operating cost while only slightly affecting effectiveness. For example, the combined scenario (1, 2, and 3) may be quite attractive, as it results in the lowest operating cost while only slightly affecting the effectiveness measures.

**Results and analysis of scenario for improving performance levels (route-splitting scenario)**

The DEA model was run again to estimate the efficiency and effectiveness scores of the bus routes for the route-splitting scenario. The efficiency and effectiveness scores for all routes (including the split routes) are shown in Figure 7.

The performance levels of all routes are summarized in the classification matrix form in Table 7. It is clearly evident from the table that the splitting-routes scenario resulted in improving the performance level for route 950 and for one part of route 930 (930B). Route 930A was performing efficiently but still ineffectively. The reason for such ineffectiveness might be the considerably low passenger demand on this part of the route. It is to be noted that some routes (e.g., route 900) were negatively affected by this scenario. The overall performance level of all routes was improved. As can be seen, no route was performing fairly efficiently and ineffectively.
Figure 7. Efficiency and effectiveness scores for all routes for split route scenario

Table 7. Classification of Al Ain Bus Routes According to Efficiency and Effectiveness Scores (Route-Splitting Scenario)

<table>
<thead>
<tr>
<th>Effective</th>
<th>Fairly Effective</th>
<th>Ineffective</th>
</tr>
</thead>
<tbody>
<tr>
<td>Efficient</td>
<td>930B</td>
<td>960</td>
</tr>
<tr>
<td></td>
<td>950A</td>
<td>990</td>
</tr>
<tr>
<td></td>
<td>950B</td>
<td></td>
</tr>
<tr>
<td>Fairly efficient</td>
<td>940</td>
<td>900</td>
</tr>
<tr>
<td>Inefficient</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Conclusion
In this paper, the efficiency and effectiveness of the Al Ain public bus service was measured and analyzed for different scenarios. The Data Envelopment Analysis (DEA) technique is very useful for measuring such efficiency and effectiveness in a situation when there is no historical data for bus service available to compare it with the current condition. The demonstrated scenarios indicated that strategies can be deployed to reduce operating hours with very little impact on the current efficiency and effectiveness measures. This may help the transit authority to cut operating cost or providing room for a better working environment for operators.
Other scenarios to enhance service and increase the efficiency and effectiveness measures were also demonstrated. Such scenarios can be systematically and intuitively developed to enhance transit system performance in the city.

The study employed a limited number of input and output variables. Only four input and two output variables were used in the DEA model to measure performance levels. It should also be noted that no exogenous or environmental factors (factors that are not under management control) have been considered in this study. It is worth noting that some of the literature considered exogenous variables (e.g., Barnum et al. 2007, 2008). These exogenous variables were used to “adjust” the values of some of the output variables to the DEA model—for instance, the use of population and route characteristics variables to adjust “ridership” using a regression model (Barnum et al. 2008). It is true that the presented models did not account for exogenous variables, which may be regarded as a limitation, but, nonetheless, it is believed that the selected input and output variables were collected accurately, and, as such, the obtained efficiency measures are reasonably accurate. These efficiency scores are to be regarded as the true or managerial efficiencies (Barnum et al. 2008). Enriching the input database with more data on the actual operating and maintenance cost and incorporating the exogenous variables to adjust the true efficiency scores could have resulted in a more sound assessment of the system and more reliable model results. However, these data were not accurately available for use.

The practical benefits of this approach are evident. It can be used by the transit authority to assess the performance measures of its services, especially when only limited data are available. It can also be used to assess various strategies to enhance service. This paper has demonstrated through examples how the DEA model can be used to enhance the operating environment, reduce operating cost, and enhance the performance levels of the inefficient or ineffective routes.

Further extensions of this work entail enhancing individual route performance to meet multi-criteria objectives. In this paper, the efficiency and effectiveness measures were tackled individually. The strategies may entail risk; for instance, it may result in better efficiency but poor effectiveness, or vice versa. Another appealing approach would entail developing a generalized performance function, including various vehicle, operator, user, and safety performance measures with various weights. This generalized function could then represent the (output) basic measure to enhance system performance. Coupling such generalized performance functions with the DEA model would provide a good balance to satisfy the needs
and safety requirements of users and yet take into consideration the operating constraints and resources.

**References**


Nash, A. 2006. Design of effective public transportation systems. 6th Swiss Transport Research Conference, Monte Verita, Ascona, Switzerland.


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An Emergency Evacuation Planning Model for Special Needs Populations Using Public Transit Systems

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Abstract

The need to have evacuation plans in place for ready implementation for special needs populations became evident after catastrophic events such as Hurricane Katrina. For the purpose of this study, special needs populations will include, but are not limited to, people with physical disabilities, older adults, non-English-speaking populations, residents and employees without vehicles, and tourists. The main objective of this study was to evaluate different evacuation procedures for special needs populations from large urban areas using current public transit systems. A microscopic simulation model was constructed to analyze real-life scenarios for evacuation methodologies. A linear programming optimization model was developed to find the optimum locations for evacuation bus stops for the case study area. The results from this study are very interesting and can aid evacuation planners in the future.

Introduction

In the past decade, large catastrophic events such as terrorist attacks and natural disasters have disrupted regional urban areas and raised awareness of mass evacu-
Advancements in technology are allowing planners to develop more efficient and effective emergency preparedness strategies to protect the general public from danger (Laben 2002). It has become evident that our society faces many dangers, and being prepared for them is one means of defense.

Catastrophic events are inevitable and pose great threat to our society. Depending on the size and demographics of the evacuation area and the type of event, evacuation procedures can vary. Through the use of reproducing traffic network behavior, simulation models provide realistic results that aid in effective evacuation planning (Di Gangi et al. 2009; Mastrogiannidou et al. 2009). The threat of man-made or natural disasters disturbing everyday life has created a need for emergency evacuation methodologies to be common knowledge to the public for quick implementation of such procedures (Mannan and Kilpatrick 2000). To be capable of quick response, city officials should have a plan of action already in place to vacate highly-populated urban areas at risk.

The type of evacuation methodology executed is also dependent on the location and size of the area being vacated. The population and infrastructure of a city can differ based on the time period and location of its establishment. Urban areas tend to have many residents living very close together with varying demographics. To efficiently evacuate all citizens of an area, particular needs of certain groups of citizens need to be taken into consideration. The issue of evacuating special needs population has become more prevalent with current events such as Hurricane Katrina (Litman 2006). The difficulty in evacuating populations with special needs varies based on the extra assistance needed by those individuals.

The aftermath of the terrorist attacks on New York City and the Pentagon on September 11, 2001, demonstrated the importance of evacuation and disaster planning for highly-populated urban areas. Large numbers of citizens are concentrated in these areas, especially during workdays, creating a vulnerable target for terrorists. These areas with high concentrations of population can lead to high casualty rates if they are not evacuated quickly. Road networks become fully saturated in evacuation scenarios due to a large number of vacating vehicles; using public transit is one alternative to improve the level of service during evacuation procedures.

Without proper planning, public transit systems can falter in the aid of emergency evacuation (Renne et al. 2008). Bus drivers need to be aware if they are required to provide services during evacuations and, if so, the location of evacuation bus stops and routes.
This study focuses on developing a public transit routing scenario to best serve special needs populations in the downtown core area of the District of Columbia (Washington, D.C.). The main goal of this study was to evaluate different evacuation procedures for special needs populations from large urban areas during a no-warning emergency using current public transit systems. For the purpose of the study, special needs populations include, but are not limited to, people with physical disabilities, older adults, non-English-speaking populations, residents and employees without vehicles, and tourists. The specific objectives to reach this goal are as follows:

- Propose optimum locations for evacuation bus stops.
- Construct a realistic microscopic simulation model of a transportation network.
- Reduce evacuation time for public transit vehicles through optimum bus stop locations.

A major part of Washington, D.C. metropolitan area being evaluated for this study includes one of the busiest Metrorail stations in the metropolitan area, Gallery Place/Chinatown station. The current infrastructure and public transportation systems presently in place in Washington, D.C. were used to hypothetically evacuate the entire population of the core downtown area. All the evacuation scenarios included ensuring that populations with special needs were evacuated as well. Through the use of computer modeling, different emergency evacuation methodologies and scenarios were assessed. Emergency evacuations are becoming more commonplace, and metropolitan planning organizations (MPOs) and transportation engineers are assessing these new planning requirements, especially in the case of the nation’s capital.

**Literature Review**

Transportation networks can be evaluated on three different levels, depending on the purpose of the analysis: microscopic, mesoscopic, and macroscopic. As traffic computer simulations evolve, hybrid models are meshing components from several different models to better represent real traffic networks (Lerner et al. 2001; Burghout et al. 2005). Microscopic scales prove to be more effective for smaller road networks, given the large number of inputs needed to build and calibrate the models (Mastrogiannidou 2009; Chiu and Mirchandani 2008; Lerner et al. 2001). A study that used a hybrid simulation platform of micro and mesoscopic analysis was performed by Coolahan et al. (2009). In their study, the Traffic Simulation System
AIMSUN NG 6.0 was used to perform microscopic and mesoscopic simulations on the Baltimore, Maryland, road network in the case of a smallpox release.

Chen and Zhan (2008) conducted an agent-based modeling study on three different types of road networks—a grid network, a ring road structure, and a real road network (see Figure 1)—proving that, “there is no evacuation strategy that can be considered as the best strategy across different road network structures and the performance of the strategies depends on both road network structure and population density” (Chen and Zhan 2008, 26).

For the purpose of this study, only one type of network, the road structure of Washington, D.C., was used to find the shortest evacuation clearance time when implementing different public transit strategies. Degnan et al. (2009) used one road simulation network to evaluate and compare several different types of evacuation methodologies. The four main strategies included nearest exit, reference, management, and staged. The “nearest exit” strategy used the shortest distance traveled from the event location to the exit location in order to evacuate the network. The “reference” strategy evacuated cars based on the exits that were assigned in advance according to network characteristics. The “management” strategy applied various management policies based on local agency requirements and procedures, such as those of the police department, city planning office, etc. The “staged” strategy evacuated the network in stages based on the previously-determined Traffic Analysis Zones (TAZs) and network capacity. The analysis was based on three different measure of effectiveness: evacuation time, total travel time, and lost vehicles. The evacuation methodology “reference” scored the lowest, with the other three methodologies yielding close results.

Liu et al. (2008) performed a corridor-based evacuation of Washington, D.C. assuming a terrorist attack on Union Station and evacuating only the six surrounding TAZs (see Figure 2). Using a GIS-based input module, they were able to determine the amount of flow on surrounding evacuation corridors. Studies focusing on communal transport, such as buses, to aid in mass evacuation for highly-populated areas are starting to become more common after the effects of Hurricane Katrina and Rita (He et al. 2009). When using buses for evacuation purposes, the main goal is to minimize the delay and the distance a bus has to travel in order to maximize the number of trips the bus can make in and out of the network (Johnston and Nee 2006). He et al. (2009) proposed a hybrid Artificial Neural Network (ANN), a mathematical model that is inspired by the structure of biological neural networks, composed of a general algorithm and climbing method to solve a location-routing
Figure 1. Simulated road networks: (a) grid road network, (b) ring road network, (c) real road network

Source: Chen and Zhan (2008)
problem for transit-dependent residents. They ran two scenarios—a one-stage and a two-stage transit evacuation using buses in Gulfport, Mississippi. This study did not incorporate a staged evacuation procedure but did not rule out buses making round trips to pick up more evacuees.

Source: Liu et al. (2008)

**Figure 2. Impact area of emergency incident**

Terrorists are aware of the vulnerability of public transit systems and have begun to target them directly. With time and advancing technology, terrorist attacks on public transit systems are becoming more severe and a larger threat. Bus, rail, and metro stations are attractive targets for terrorists because of the large congregation of passengers, such as a crowded bus with standees or a downtown subway platform at rush hour (Rabkin et al. 2004). Other than just the crowds that generate a terrorist’s focus, the public transport system can supply the means or ends of a terrorist attack.
Methodology

Considering the large size and specific demographics of special needs populations located within the boundaries of the microscopic simulation network, origin-destination matrices (O-D) were used to produce the traffic demands. The safe zones were used to represent a safe location that is a safe distance from the hazardous area and are strategically placed according to current evacuation plans in place by city officials.

To combine TAZs not occupying the virtual network, the Thiessen polygon method was used. Thiessen polygons are “mathematically defined by the perpendicular bisectors of the lines between all points” (ET Geo Wizards). For a given number of spatially-distributed points, the Thiessen polygon method is capable of producing their respective areas of influence; for this application, the contribution area is for a safe zone centroid. Using the Thiessen polygon generation feature of ArcGIS 9.3 and the nine safe zone centroids, the polygons were created and incorporated all the TAZ trip information provided by the MPO (see Figure 3).

![Thiessen polygon distribution of outer TAZs](image)
Where,

\[ T_{i,j} = \left( \frac{A_{i,j} \ast T}{A_i} \right) \]  \hspace{1cm} (1)

\[ T_j = \sum_{i=1}^{9} T_{i,j} \ \ j = 1, 2, 3 \ldots 9 \]  \hspace{1cm} (2)

\[ T_{i,j} = \begin{cases} 0 & \text{if } i \notin j \\ T_{i,j} & \text{otherwise} \end{cases} \]  \hspace{1cm} (3)

\[ T_{i,j} = \text{Trips originating in traffic analysis zone } i \text{ associated with safe zone } j \]
\[ A_{i,j} = \text{Area of traffic analysis zone } i \text{ within safe zone } j \]
\[ A_i = \text{Area of traffic analysis zone } i \]
\[ T_j = \text{Total number of trips associated with safe zone } j \]

The goal of this evacuation methodology was to relocate all people located inside the network to safe zones. The safe zones are located outside the network along major roadways that currently act as evacuation routes for the city. The simulation model used for this analysis had a total of nine safe zones (Figure 3). The safe zones are the only zones in the model that produced travel demand. This is due to the assumption of a no-warning evacuation, not allowing people to return home before evacuating. It is assumed that once vehicles in the network reach these safe points, they are no longer in harm’s way and can continue safely to shelters. The traffic demand of each safe zone was obtained based on its attractiveness as a function of the inverse distance between it and the traffic production areas.

The first step in developing the evacuation O-D matrices required obtaining the trip production for each TAZ. Using demographics obtained from the U.S. Census Bureau, trip production for personal vehicles in each TAZ was calculated using empirical equations. The number of people in each TAZ that rely on public transit for evacuation was obtained from further analysis of demographic data. To estimate the number of people without a vehicle, the total number of people using personal vehicles was subtracted from the total number of people located in that zone during the evacuation scenario. Using U.S. Census data, the number of people with physical disabilities, older adults, foreign populations, and low-income households in each TAZ was used to give that TAZ a higher priority for bus routing during evacuation.

After the number of vehicles for each TAZ was known, personal vehicle trips were assigned to safe zones. Human driver behavior is extremely difficult to predict,
especially in mass emergency evacuations (Alsnih and Stopher 2004; Degnan et al. 2009). In this analysis, the main focus was on the exit of public transit vehicles such as buses that have a fixed set route for evacuation. To have the road network properly loaded with personal vehicles in order to simulate how well bus routes serve special needs populations in an evacuation, a trip assignment procedure was developed. The assignment of personal vehicles to a particular safe zone was completed following an inverse distance relationship between the origin and the destination, as defined by Equations 4–11.

\[ V'_{z,j} = f(d_{z,j}, V, n_j) \]  
\[ d_{z,j} = \sqrt{(x_z - x_j)^2 + (y_z - y_j)^2} \]  
\[ V''_{z,j} = \begin{cases} 0 & \text{if } d_{z,j} \geq d_{\text{max}} \\ f(d_{z,j}, V, n_j) & \text{otherwise} \end{cases} \]  
\[ w_{z,j} = 1 - \left( \frac{d_{z,j}}{\sum_{j=1}^{n_j} d_{z,j}} \right) \lambda_z \]  
\[ w_{z,j} = \begin{cases} 0 & \text{if } w_{z,j} \leq 0 \\ w_{z,j} & \text{otherwise} \end{cases} \]  
\[ \lambda_z = \begin{cases} 3 & \text{if } n_j \geq 4 \\ 2 & \text{if } n_j = 3 \\ 1 & \text{otherwise} \end{cases} \]  
\[ R_{z,j} = \frac{w_{z,j}}{\sum_{j=1}^{n_j} w_{z,j}} \]  
\[ V'_{z,j} = R_{z,j} V'_{z} \]

Where:

\( n_j \) = number of safe zones (j) within \( d_{\text{max}} \) of zone (z)

\( V_{z,j} \) = number of cars in TAZ (z) to safe zone (j)

\( D_{z,j} \) = distance between TAZ (z) and safe zone (j)

\( w_{z,j} \) = “attractiveness” for cars from TAZ (z) to safe zone (j)
\( \lambda_z = \text{adjustment factor for each TAZ (z) as a function of the number of safe zones (j) within } d_{\text{max}} \)

\( d_{\text{max}} = \text{maximum distance for a safe zone to be a feasible safe zone} \)

\( x, y = \text{coordinates of z and j} \)

\( R_{z,j} = \text{"attractiveness" ratio} \)

The distance of each TAZ to all safe zones was found using the centroid of the zone. The centroids of each traffic zone were found by implementing Hawth’s Analysis Tools for ArcGIS 9. The latitude and longitude for each TAZ and safe zone centroid were then documented and used to find the Euclidean distance.

**Mathematical Model of Bus Stop Locations**

The goal of this mathematical model is to maximize the overall benefit of evacuation bus stops located within the case study area using linear programming with binary variables. The objective function and constraints are presented as follows:

Maximize \( \sum_{b=1}^{B} \beta_{b,z} \phi_{b,z} \quad \forall \, z \) \tag{12}

Subject to:

\[ \beta_b = w_m \sum_{m=1}^{M} \left( \frac{1}{d_{b,m} \psi_{b,m}} \right) + w_v \sum_{v=1}^{V} \left( p_v \ast \frac{1}{d_{b,v} \psi_{b,v}} \right) + w_l \sum_{l=1}^{L} \left( p_l \ast \frac{1}{d_{b,l} \psi_{b,l}} \right) \] \tag{13}

\[ + w_e \sum_{e=1}^{E} \left( p_e \ast \frac{1}{d_{b,e} \psi_{b,e}} \right) + w_o \sum_{o=1}^{O} \left( p_o \ast \frac{1}{d_{b,o} \psi_{b,o}} \right) + w_s \sum_{s=1}^{S} \left( p_s \ast \frac{1}{d_{b,s} \psi_{b,s}} \right) \quad \forall \, b, z \]

\( N_{z}^{\text{max}} = f(T_z, A_z) \quad \forall \, z \) \tag{14}

\( N_{z}^{\text{max}} = \sum_{b=1}^{B} \phi_{b,z} \quad \forall \, z \) \tag{15}

\[ \sum_{z=1}^{Z} \phi_{b,z} \leq \eta \quad \forall \, b \] \tag{16}

\( \phi_{b,z} = \{0,1\} \) \tag{17}
An Emergency Evacuation Planning Model for Special Needs Populations

\[ N_{z}^{\text{max}} = \begin{cases} \frac{A_{z}}{A_{b}^{\text{max}}} & \text{if } \frac{A_{z}}{A_{b}^{\text{max}}} \geq \frac{T_{z}}{T_{b}^{\text{max}}} \forall b, z \\ \frac{T_{z}}{T_{b}^{\text{max}}} & \text{otherwise} \end{cases} \]  

(18)

\[ N_{z}^{\text{max}} = \begin{cases} 0 & \text{if } N_{z}^{\text{max}} \leq \xi \\ N_{z}^{\text{max}} & \end{cases} \]  

(19)

Where,

\( \phi \) = binary decision variable

\( \beta \) = benefit of bus stop

\( b \) = bus stop

\( z \) = traffic analysis zone

\( N \) = number of bus stops

\( m \) = Metrorail station

\( d \) = distance

\( \psi \) = distance factor

\( v \) = persons that do not own a vehicle

\( e \) = persons over the age of 65

\( l \) = person with a low income below poverty line

\( s \) = persons with physical disabilities

\( y \) = employees

\( w \) = weight defined by the decision maker to a criteria category

\( p \) = size of special needs population

\( T \) = bus trips required to evacuate special needs population

\( A \) = area

\( \zeta \) = minimum \( N_{z}^{\text{max}} \) value necessary to have a bus stop

\( \eta \) = maximum total number of bus stops for the entire study area
The objective function is to maximize the overall benefit of chosen evacuation bus stops. Binary variables \( \phi_{b,z} \) are decision variables within the optimization model used to define which bus stops are chosen, constrained by a maximum number of bus stops per TAZ \( N_{z}^{\text{max}} \) and also for the area of study \( \eta \). The optimization assigns a maximum number of bus stops to each TAZ within the case study area (Eqs. 14, 15, 18, 19). The total number of bus stop locations that can be selected for the area is set be Eq. 16. The criterion for selecting evacuation bus stops is associated with the weighted bus stop benefit \( \beta_{b,z} \). For bus stops that are selected, the binary variable assumes a value of 1, so that the benefit is added to the objective function.

The benefit associated with each bus stop is based on a function that aggregates distance and population attributes associated with each bus stop (Eq. 13). The specific benefit of bus stations is based solely on its inverse distance to a given bus stop. However, for other groups of interest, such as special needs populations, the size of population \( p \) of each special needs group will introduce another factor to the benefit function. For instance, a bus stop located near a larger population of people with physical disabilities will have a higher benefit than a lower population for the same given distance.

In an evacuation scenario, using all available bus stops is not a feasible solution based on time constraints. Therefore, a maximum number of bus stops \( \eta \) needs to be specified to reduce delay times related to frequent stops (Eq. 16). Moreover, the objective function that attempts to maximize the overall benefit of bus stops can lead to the optimum location of bus stops to be clustered in one area, representing the greater benefit value in the whole study area. Eq. 15 was introduced to inhibit a grouping of bus stops in each TAZ. By dividing the study area into several different TAZs, a maximum number of bus stops can be defined per zone, limiting the number of bus stops in one TAZ area. The maximum number of bus stops that can be chosen for a zone \( N_{z}^{\text{max}} \) is a function of bus trips required and area of the zone, as defined by Eq. 14. This model allows for the decision maker to determine how many trips one bus stop can serve. That maximum number of trips \( T_{\text{max}} \) is then divided by the entire number of trips required for the zone, producing the number of needed bus stops. The decision maker must also decide what the maximum square area will be for requiring a bus stop. The entire square area of the zone is then divided by this set area, and another number of needed bus stops is produced. The formulation then uses the larger of the two values to set equal to \( N_{z}^{\text{max}} \). If the total number of trips needed and the area of a zone do not reach a set value \( \zeta \),
it is reasonable to assume that $N_z^{\text{max}}$ can equal 0, stating that no bus stops will be assigned to that particular zone.

Other constraints can be defined to specify the desired number of bus stops for a specific TAZ, overriding the function previously described. If one particular TAZ was not assigned an evacuation bus stop and the need for a bus stop at that particular location is understood by the decision maker, an equality or inequality constraint can be declared. For example, for $z = 23$, no bus stop was originally assigned, but by declaring Eq. 20 as a constraint, three bus stops are enforced:

$$N_{23}^{\text{max}} = 3$$  \hspace{1cm} (20)

Once the total benefit for evacuation bus stops is reached, it is important to note the location within the entire case study. The purpose of this model is to maximize the evacuation of a specific demographic. The combination of a limited number of available bus stops ($N^{\text{max}}$) and bus stops with low benefit value may cause certain areas not to have any assigned bus stops. The constraint presented in Eq. 20 may overcome this issue; however, if a larger area encompassing several TAZs does not contain any selected evacuation bus stops, the decision maker may declare another constraint so that the optimization will assign to the referred area a given number of bus stops based on selecting those with a greater benefit. For example, if four TAZs ($z=10,11,12,13$) have very small special needs populations and no bus stop is identified within this area, as the associated benefit is low compared to other areas, the decision maker can declare the constraint to still include them within the model:

$$N_{10}^{\text{max}} + N_{11}^{\text{max}} + N_{12}^{\text{max}} + N_{13}^{\text{max}} \geq 1$$  \hspace{1cm} (21)

If the decision maker finds that the optimum bus stop locations are clustering in one region of the evacuation area, and applying constraints such as Eq. 21 would become too repetitive, the area can be spatially divided. By dividing the area into smaller sub-sections, zones can be grouped together, and a minimum number of bus stops can be set for the sub-section. This would allow a more even spatial assignment of evacuation bus stops. Despite the complexity of the given formulation, the model proves to be flexible, satisfying the decision maker’s needs in evacuation planning for all study areas.

The computational time requirements to achieve the optimal solution were minimal, approximately three seconds. For comparison purposes, the same formulation was optimized using a Genetic Algorithms solver, requiring considerable computa-
tional time for the convergence to the same optimal solution. It was then decided that a linear programming approach was the best for this research.

Case Study
For this study, the downtown core area of Washington, D.C. was selected to be analyzed. The challenges faced in evacuating this specific area incorporate the large diverse urban population, prestigious government buildings, a complicated road network, and a significant quantity of population that depends on public transportation. Reported by the U.S. Census Bureau, the District of Columbia had a population of 591,833 in 2008. On weekdays, this figure can increase by 72 percent, with an additional 410,000 people entering the city for business purposes (Longley 2005).

The nation’s capital has one of the most efficient public transit systems in the country, operating under the Washington Metropolitan Area Transit Authority (WMATA). The Washington Metropolitan Area Transit Compact joined public and private transit companies in its jurisdiction in order to have an efficient regional transit service.

Current evacuation plans for Washington, D.C. are composed of 19 major corridors. Secondary route choices have also been designated by the District Department of Transportation (DDOT), allowing for flexibility to transfer from one primary exit route to another if needed. These routes are defined in the evacuation map of Washington, D.C. in Figure 4.

A microscopic simulation model of the Washington, D.C. core downtown area was constructed in the simulation platform AIMSUN NG 6.0. AIMSUN uses object-oriented simulators and a graphical user interface to produce 2D/3D animations of the road traffic network. Real traffic conditions for different road networks can be modeled in AIMSUN using built-in functions such as lane changing, car following, and gap acceptance (Xiao et al. 2005; Barcelo et al. 2004).

All signalized intersections were calibrated using the signal optimization software Synchro. Three sets of signal timing files were collected in total: AM peak hours (7am to 9am), Midday-off peak hours (10am to 2pm), and PM peak hours (3pm to 7pm). To calibrate and validate the road geometry and signal timings of the computer model, everyday background traffic was used. Everyday traffic demand was provided in O-D matrices and was validated using 2006 traffic counts from DDOT. These everyday O-D matrices were received from the agency through the Metropolitan Washington Council of Governments (MWCOG), the National Capital Region Transportation Planning Board (TPB). The everyday matrices were used
to produce background traffic on the model before the evacuation commenced and validated the model when compared to traffic counts. The O-D matrices were given in the computer software package Cube Voyager.

Results
The results of the research fall into two main categories: the mathematical model and the simulation model. The simulation model was dependent on the results found from the optimization model. After reviewing the results from the optimization model, it was decided to execute the model for a second time with added spatial constraints before simulating the results.

Mathematical Model Results
The mathematical results yielded the total benefit of evacuation bus stops according to the weighting scheme and maximum number of bus stop occurrences, both of which are dependent upon the decision maker’s preferences.
It was noted that the there is some relationship between the individuals found in the categories chosen for the mathematical model. Persons who choose not to own a vehicle could be influenced by a low income. Older adults and persons with physical disabilities might find it difficult to work and result in falling into the category of low income as well. Considering this relationship, an individual might be accounted for twice. Therefore, a weighting scheme was developed to carefully account for all special needs populations without overemphasizing one group or another.

Finding a correlation between the categories was not possible due to the fact that some of the data for certain categories was based on percentages of total population, resulting in an inaccurate correlation very close to 1. A sensitivity analysis was performed to find the most representative weighting scheme for the given case study area. The optimization model was executed 10 times for each maximum number of bus stop occurrences ($\eta$). For each weighting scheme, the frequency that the $\eta$ best ranked bus stops occurs for all weighing schemes and for all $\eta$ maximum number of bus stops scenarios was graphed. The scenario that most frequently selected the same bus stop locations for all 10 scenarios was then chosen for simulation purposes. The weights adopted for weighting scheme 6 produced the best weights for bus stop locations in the application of this case study because of the weights being distributed evenly among all the special needs population categories.

The bus stop locations yielded from the optimization model proved to have the highest benefit for special needs populations in the downtown Washington, D.C. core area. As expected, the total benefit increased as the total number of maximum optimum bus stops increased. Each condition always included the optimum bus stops selected in the preceding condition.

The total benefit found for the 20 bus stop locations was 42.88 and was one of the highest among all 10 of the weighting scenarios for the 20-maximum-bus-stops scenario. Even though this scenario produced one of the highest benefits, the location of bus stops is not ideal for planning purposes, because the majority of selected stops were located and clustered in the area northwest of the White House (Figure 5a). Therefore, the majority of the downtown area does not contain any evacuation bus stops. The low number of evacuation bus stops with the addition of clustering results in only a few TAZs containing evacuation stops, leaving most of the zones empty without any evacuation bus stops.
Figure 5a. Optimum 20 bus stops from trial 1

Figure 5b. Optimum 40 bus stops from trial 1
When the maximum number of bus stops was increased to 40, the benefit of the bus stops also increased, to 68.3. This is a likely result in that the more bus stops selected, the more benefits the objective function will contain to sum. The bus stop locations seem to have an improved spatial spread throughout the downtown area. When examined closely, one can see a lack of evacuation bus stops in the lower third portion of the region, as well as the northeast corner. The lower portion of the case study area includes the National Mall and attracts many tourists daily. Therefore, it is vital that an evacuation bus stop is located in this area; extra constants were added to the formulation to account for this area (Figure 5b). This represents one of the biggest limitations of the study since very fine demographic data are required to properly represent the special needs population when calculating the benefit of bus stops. Collecting demographic data at the TAZ or census tract level is too broad to calculate the benefit of bus stop locations. Demographic data need to be collected at a finer level such as census block. Obtaining demographic data from the U.S. Census Bureau at the census block level produces a challenge because a majority of data is not readily available at this level.

After adding another 20 bus stops for a total maximum number of 60 bus stops (Figure 5c), the maximum total benefit increased to 79.32. By allowing the model
to choose 60 bus stop locations, the greatest benefit was achieved and the overall spatial distribution was greatly improved.

After reviewing the results of the mathematical formulation, the model was implemented for a second time to obtain results that would be more practical for actual planning purposes, even if a lesser number of maximum bus stops than 60 is required. The first set of bus stop location results yielded the stops with optimum benefit for special needs populations but did not take into account the travel time of the evacuee to reach the bus stop. If resources were available for 20 or 40 maximum evacuation bus stops, the optimization model will need to introduce additional constraints.

In an actual evacuation, bus stop locations must be available for service throughout the entire network and not in just one concentrated area. Despite that, this concentrated area is the one that resulted in the largest benefit, and it is understood that the bus stops should be more spatially distributed to serve all special needs populations throughout the entire downtown area to comply with practical evacuation planning. To prevent non-special needs people from taking the designated spaces of those with special needs, a priority policy should be implemented.

**Simulation Results**

The simulation results for this research are presented using specific measures of effectiveness: delay time (sec/mi), travel time (sec/mi), and stop time (sec/mi). All results presented are for buses only (the main objective of this research is focused on evacuation of public transit vehicles). A standard dwell time was calculated and applied to all evacuation bus stops. Using standards set by the *Highway Capacity Manual* (TRB 2010), a dwell time of 297.5 sec was calculated. Results were recorded for five different replications for the five different maximum number of evacuation bus stop location scenarios.

By routing the evacuation buses to the nearest evacuation corridor, an attempt was made to keep delay time to a minimum. The largest delay time was experienced by the 40-bus-stop scenario (324 sec/mi). The buses in the 20-bus-stop scenario could be experiencing a high delay (309 sec/mi) because of the congestion of all the buses serving the same small number of stops. The buses in this scenario had to be set to a very close headway (approximately 2 min) to reach the required number of bus trips to evacuate the case study area. Due to the minimum headway interval and large dwell times, the delay experienced was significantly higher than in other scenarios.
time, buses serving the same stop formed larger queues than in the other scenarios. The lowest delay time was experienced by the 60-bus-stop scenario (277 sec/mi).

The travel time for each individual evacuation bus is dependent on the route of the evacuation bus. Several bus routes extended through the entire case study area, while others traveled just along the perimeter. The routing strategy implemented in this research tried to reduce travel time by exiting all evacuation buses to the nearest evacuation corridor after serving its assigned stop. Travel time is also dependent on which roadways the bus route serves and its level of service. The results found for travel time are consistent with the results obtained for delay time. This is due to delay time having a linear relationship with travel time experienced by the evacuation bus. If a bus experiences a larger delay time, the travel time will also increase. The average travel time for all the evacuation buses increased until reaching the 40-bus-stop scenario (399 sec/mi). Again, the 40-bus-stop scenario had the highest result compared to other replications. On average, the travel time was lower for bus stop scenarios that contained more than 40 evacuation bus stops. The lowest average travel time resulted from the 60-bus-stop scenario (355 sec/mi). The ranges for average travel time among all five scenarios were all within 50 sec/mi. This might seem to be a minor difference, but when dealing with evacuation, time is of the essence.

The stop times found for each replication bus-stop scenario also followed the same patterned of the two previous sets of results. Replications for the 40-bus-stop scenario had the largest stop time when compared to the stop times for the other scenarios (298 sec/mi). The 60-bus-stop scenario had stop times that were that were the lowest of all the scenarios (252 sec/mi).

The 40-bus-stop scenario yielded the highest delay, travel, and stop times and should not be implemented for evacuation. This could be due to the bus stop locations still requiring a large number of evacuation trips. It can be seen once the simulation is set for the 50-bus-stop scenario and the number of required trips per bus stop decrease from 50 to 40, reducing the delay, travel, and stop time. Also, the bus routes required for this scenario might require longer evacuation travel distances.

After reviewing all the results for each measure of effectiveness, it can be seen that the 60-bus-stop scenario produced the most efficient evacuation time. Its delay, travel, and stop times were all the lowest when compared to the other simulated scenarios. This is due to the lower number of required buses per evacuation stop causing queues at evacuation stops for waiting evacuees. Furthermore, the stops were more evenly spatially distributed in this scenario, allowing for evacuation buses to slow evacuating traffic equally in the case study area and not just in con-
centrated sections. More bus stop locations are located along the perimeter of the case study area, allowing for shorter bus evacuation routes.

Table 1 illustrates the delay time values obtained from the simulation runs for each scenario. Table 2 shows the stop time results, and Table 3 shows the travel time replication results for each of the five scenarios.

**Table 1. Replication Results for Delay Time**

<table>
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<tr>
<th>Max # of Stops</th>
<th>1</th>
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<th>3</th>
<th>4</th>
<th>5</th>
<th>Average</th>
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**Table 2. Replication Results for Stop Time**

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**Table 3. Replication Results for Travel Time**

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**Conclusions**

This study effectively addressed the optimal allocation of bus stops for the purpose of evacuating special needs populations. The proposed methodology was applied to a real-life case study to evaluate the effects of the location, number, and distribution of optimal evacuation bus stops. A microscopic traffic simulation model was
developed to represent the downtown Washington, D.C. area in an evacuation scenario. Input data, such as geometric design, signal timing, traffic demand, and demographics, were used to construct the simulation model.

A linear programming mathematical model using binary variables was developed to select the most suitable location and number of bus stops catering to special needs populations in the network. A benefit function aggregated the attributes associated with each existing bus stop based on spatially-distributed demographic information. The formulation incorporated the preferences of the decision makers by associating weights with each specific special needs group. The flexibility of the formulation allows the decision maker to address specific concerns of the evacuation area. The use of a linear programming technique for the mathematical model presented in this research yielded satisfactory results. As mentioned earlier, the same formulation was optimized using a Genetic Algorithms solver for comparison purposes. However, this method required considerable computational time for convergence to the same optimal solution. It was then decided that a linear programming approach was the best for this research.

Simulating the optimum bus stop locations with the simulation model that was constructed for this research, evacuation performance results were obtained. As expected, the 20-bus-stop scenario produced very poor results and did not perform well under the evacuation scenario. The 60-bus-stop scenario created a very even spatial spread of evacuation bus stops throughout the case study area. It was assumed that this scenario would have large travel, delay, and stop times because of the diverse spread of resources and addition of extra bus routes. The results proved the opposite by showing satisfactory outcomes. The simulations for the 40-bus-stop scenario produced the highest results for all five replications. The 40-bus-stop scenario would not be ideal to implement for evacuation purposes for this case study. Each bus stop scenario that contained a greater number of bus stop locations performed superior. If the case study area has the resources to provide 60 evacuation bus stop locations, this scenario would be best for planning purposes. This scenario had the lowest delay, travel, and stop times with the best spatial spread of evacuation bus stops.

**Limitations**

The task of calibrating a large microscopic traffic network is one that requires the user to be familiar with the traffic conditions of the case study area and an ample amount of time to reconstruct the traffic conditions. Calibration is a very time-consuming task and was a notable limitation in this research. The task of establish-
ing origins and destinations does not take into account the travel path of vehicles, leaving the route choice model to determine vehicle paths. Traffic simulation includes considerable uncertainty, as it attempts to model human behavior which is very random, especially while simulating an evacuation scenario.

Several recommendations are made if this work is to be furthered.

- Some sort of penalty could be devised for bus stops that are located too close to each other to avoid clustering to add in the optimization formulation. Further grouping of TAZs could be developed to reduce the effects of clustering. A grid grouping method was introduced in this research but did not sufficiently separate the evacuation bus stop locations.
- The relationship/correlation between demographic groups could be explored further in order to avoid overemphasizing individuals that fall into multiple categories. Other implementations could include new target demographic groups. Census data for the specific demographic groups could be collected at the census block level instead of applying a percentage to the total population of the census block.
- The simulation portion of this research could be extended to explore more possibilities for evacuation planning. Different evacuation bus routes could be simulated, as could different headways and frequencies in which the buses depart or pick up evacuees. This research was limited to selecting optimum evacuation bus stop locations that currently act as bus stops in the everyday operation of the city. Future work could explore the possibility of using new bus stops that are not currently in use for everyday practice.

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The Impact of Bus Door Crowding on Operations and Safety

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Abstract

This study examines how bus design factors influence door crowding and quantifies how door crowding relates to operational performance and passenger safety. Results are based on data collected for 2,807 stops in Dhaka, Bangladesh. Door crowding is affected by multiple bus design factors, including door placement, aisle length, presence of a front seating area, and service type. Increases in door crowding are associated with longer marginal boarding times and an increased number of unsafe boarding and alighting movements that occur when the bus has not come to a complete stop. Results underscore the importance of educating conductors on the dangers associated with door crowding.

Introduction

Crowding within transit vehicles is an unstudied aspect of many systems. Although there is recognition that crowding by the door can affect operations and safety (e.g., many metro rail systems post “Do Not Stand in Doorway” signs), the underlying ways in which crowding affects operations and safety are not well understood. Crowded vehicles are a sign of healthy ridership, but regulating the extent to which vehicles get crowded may benefit passenger safety and vehicle performance at the curb. The Transit Capacity and Quality of Service Manual recognizes that in-vehicle circulation can be hindered by crowding, acknowledging that “boarding and alighting occurs more slowly when standees are present. The amount of space available
for standees ... influence[s] how passengers circulate within the vehicle” (Kittelson & Associates 2003).

The objectives of this study are to (1) investigate how bus design factors influence door crowding and (2) quantify how door crowding affects operational performance and safety. This study is unique in that it shows that crowding near door areas is the critical part of the internal space that affects operational performance.

Background
Dhaka's transportation system consists of a large number of modes that operate on infrastructure that does not meet the city's demand needs. Katz and Rahman (2008, 2010) describe the system in depth, noting the prevalence of non-motorized transportation and the role buses play in the population's mobility. The large majority of Dhaka's buses are privately-operated and carry the largest portion of motorized trips. Competition along routes is high, often with several operators from both “ticket” and “local” services. Ticket buses have one conductor who collects tickets at the door, and stops on the route are denoted by ticket sellers at tables. Local buses collect fares on-board with the use of two conductors; their stops are set but unmarked. For both bus services, the conductor chooses whether passengers are allowed to board and alight between stops. Local buses, for the most part, always allow this to occur between stops. Ticket buses are less likely to allow boarding and alighting between stops, but it does occur regularly.

Dwell time, which refers to time between the bus wheels stopping and starting, varies greatly on a conductor’s desire to wait for passengers. The bulk of boarding and alighting activities, however, occurs at the beginning of the stop, and it is the variation in this portion of the dwell time that is studied in this paper.

Knowledge and insight into the transportation system of Dhaka comes from the first author’s year on a Fulbright Scholarship in Dhaka. While there, he worked with Dr. Md. Mizanur Rahman at the Bangladesh University of Engineering and Technology and gained experience with the system by riding the bus system 10 hours each day.

Literature Review
This section describes Dhaka's bus system and summarizes key points from the literature related to how crowding occurs on buses, is typically measured, and affects operational performance.
Dhaka is the largest urban area in Bangladesh and does not have an organized bus system or a rail mass transit system (Andaleeb et al. 2007). Dhaka’s bus system, which is the primary public transportation mode for the city, is operated by dozens of private operators. City management has not provided the appropriate facilities for buses to operate, and the current number of operating buses does not meet passenger demand (Andaleeb et al. 2007). The lack of managerial oversight combined with unreliable schedules, unpublished time tables, and aggressive market competition have caused Dhaka’s buses to become overcrowded (Zahir et al. 2000). Operators seek to maximize profits, which often results in long dwell times at major stops. In addition, operators often skip minor stops and/or do not come to a full stop at these locations for alighting passengers. Users and non-users alike indicate that these types of service deficiencies, particularly discomfort and congestion inside the bus, deter them from riding (Hoque and Hossain 2004). However, despite these complaints, Dhaka’s buses still carry more than half of the passengers in motorized vehicles on Dhaka’s streets (The Louis Berger Group 2005).

Crowding can make transit undesirable for passengers, even though a crowded bus indicates high levels of ridership (Perk et al. 2001). When passengers are unable to board or have difficulty boarding a bus due to overcrowding, the perceived quality of service is drastically decreased (Fernandez and Tyler 2005). Congestion inside the bus prevents passengers from being able to circulate freely for boarding, alighting, and finding a place to stand or sit (Fritz 1983). Some authors, however, have noted that the interior design of buses can be better designed to handle crowding so that it is more comfortable for passengers and reduces the serious negative effects (Kogi 1979).

Although operational performance can be influenced by multiple factors, several studies have noted that because human factors are too variable (such as conductor and driver behavior) and cannot be predicted for the future (Lin and Wilson 1992), it is better to look at aspects of transit operation that directly and predictably affect boarding and alighting rates, including crowding. For example, Kraft and Bergen’s (1974) study is one of the first that found crowding inside vehicles had an effect on operations. They found that passengers boarding and alighting were often delayed, resulting in an increase beyond the transit vehicle’s expected service time.

A variety of measures have been used to describe crowding and evaluate its effect on dwell time, but no universal measure has been developed to fully understand the effects of crowding on safety and operational performance measures. Examples of measures in the different studies include the gross number of passengers on-board (Zografos and Levinson 1986), the gross number of standing passengers (Lin
and Wilson 1992), a “friction” factor based on the number of standing passengers (Dueker et al. 2004), a categorical measure of the volume (Fritz 1983) and load factors (Aashtiani and Iravani 2002; Rajbhandari et al. 2003). Load factor, however, which is often tracked by transit agencies, is not always effective in capturing what is occurring on-board because it relates to the number of seats and, thus, a large load factor could indicate a very crowded bus or a bus with few seats (Seattle DOT 2007). For this reason, measures that capture vehicle capacity based on both standing and sitting passengers who can safely and comfortable ride are generally considered to be more insightful.

Many of these studies noted above have found that as a bus becomes increasingly crowded, dwell times increase and passenger processing rates suffer, whether linearly or non-linearly. Crowding measures, however, are not always significant in explaining increases in dwell time, as seen in a study by Rajbhandari and colleagues (2003).

It is also important to note that in many studies, the impact of crowding on dwell times is not directly modeled but rather treated as an outlier or recording error. Crowding can be used to explain the existence of data outliers (Dorbritz et al. 2009). It has provided reason to remove data from a set because heavy crowding is considered more likely to be an error (Dueker et al. 2004).

In the context of our study, it is important to note that although door crowding has not been used as a measure to examine dwell times, several studies have indicated its importance. Fernandez et al. (2010) discuss that the number of passengers standing before the fare collection point inside the bus affects operations and make use of a dummy variable in dwell time models for when only the door area is free for standing. Zografos and Levinson (1986) recognized the importance of having ample space in the door areas and note that “even when the bus was full, the time per boarding passenger did not increase for the first two or three passengers, because the reception space was adequate.” Our study expands upon this issue to create measures for crowded buses that capture this critical part of bus operations.

Methodology

This section describes the sampling frame, data collection methods, and the process used to identify observations that contained recording errors. This section also defines key terminology (e.g., early boards, late boards, door crowding).
**Sampling Frame**

Data were collected within the city limits of Dhaka, Bangladesh, from March to August 2008. Seven bus types, displayed in Table 1, were sampled to investigate how service type, bus shape, door configuration, and front seating influence crowding. Buses that provide “ticket service” collect fares curbside; the ticket is subsequently collected by a conductor as the passenger boards the bus. In contrast, buses that provide “local service” collect cash fares on-board the bus once the bus is moving. Buses can be further classified into minibuses with one door, large buses with one door, or large buses with two doors. The placement of doors on large buses is also important in the context of crowding, as different crowding patterns may emerge depending on whether the rear door is placed in the middle or back of the bus. Some one-door buses have a front seating area adjacent to the driver’s seat, generally reserved for female riders. The presence of a front seating area in the bus may also influence crowding.

<table>
<thead>
<tr>
<th>Bus Type #</th>
<th>Service</th>
<th>Bus Shape</th>
<th>Door Configuration</th>
<th>Front Seating?</th>
<th># Operators Sampled</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type 1</td>
<td>Ticket</td>
<td>Large</td>
<td>One door</td>
<td>Yes</td>
<td>3</td>
</tr>
<tr>
<td>Type 2</td>
<td>Ticket</td>
<td>Large</td>
<td>One door</td>
<td>No</td>
<td>3</td>
</tr>
<tr>
<td>Type 3</td>
<td>Ticket</td>
<td>Large</td>
<td>Two doors (front/middle)</td>
<td>No</td>
<td>3</td>
</tr>
<tr>
<td>Type 4</td>
<td>Ticket</td>
<td>Large</td>
<td>Two doors (front/back)</td>
<td>No</td>
<td>3</td>
</tr>
<tr>
<td>Type 5</td>
<td>Ticket</td>
<td>Minibus</td>
<td>One door</td>
<td>Yes</td>
<td>3</td>
</tr>
<tr>
<td>Type 6</td>
<td>Local</td>
<td>Large</td>
<td>Two doors (front/back)</td>
<td>Yes</td>
<td>1</td>
</tr>
<tr>
<td>Type 7</td>
<td>Local</td>
<td>Minibus</td>
<td>One door</td>
<td>Yes</td>
<td>7</td>
</tr>
</tbody>
</table>

The majority of Dhaka’s bus system is operated by private companies. The Bangladesh Road Transport Corporation is responsible for issuing route permits to private operators. The permits dictate the route assigned to the bus; however, route numbers are often not visible to the waiting passenger. In addition, maps and timetables are rarely available, and headways are seldom consistent for a given route. Competition among operators on routes is high, and drivers compete with other buses, including those from the same company, to collect passengers. Between the origin-destination pair of Mohammedpur and Gulistan, for example, five ticket buses and two local buses are operated.
Because there are hundreds of private operators, a stratified sampling frame was used in the study. The number of bus operators sampled for each bus type is shown in Table 1. For each operator, a route was observed six times (three times in each direction). Data were collected on weekdays when buses were crowded.

**Data Collection**

Data were collected by an observer on-board the bus who used a voice recorder. Boarding and alighting times were recorded for each passenger, as well as information on which door he/she used and at which stop the passenger movements occurred. Information on boarding and alighting times was used to calculate the total number of passengers on the bus and the time between passenger boarding and alighting movements. After all buses were ridden and all stops on each route were sampled, data had been collected for 147 bus routes and 2,807 stops.

Several operating and safety characteristics were also recorded for each bus stop. After a bus had left a stop, the number of passengers standing in the door areas of the bus was recorded. These door areas are displayed in Figure 1 and include the number of passengers standing before the front row (BFR) and the number of passenger standing in front of the back door (FBD). Any passengers sitting in a front seating area on a bus were excluded from the BFR value, as noted in the figure. The distance the bus stopped from the curb, measured in half-lane increments, was also noted for each stop. Unsafe boardings and alightings, which occurred when a bus was not fully stopped, were recorded and classified into four variables: early boards (EB), early alights (EA), late boards (LB), and late alights (LA).

As seen in Figure 2, a bus’s “stop” was defined from the point in time in which it entered the stop area—even while still moving—to its first gear change upon leaving the stop. The dwell time begins when wheels stop and ends when wheels start (and the bus actually departs from the stop location, i.e., as shown in the figure, there were cases in which a bus would start to move, then stop again to wait for additional passengers). LA and LB occur from the time period in which a bus departs the stop until the stop break point. The stop break point was defined to be (1) the point immediately after the next intersection or (2) the time at which the bus was moving at full speed. The total number of BFR and FBD are tallied at the stop break point, and any boarding and alighting after this point in time were classified as EA and EB for the subsequent stop.
The Impact of Bus Door Crowding on Operations and Safety

Definitions for Door Crowding and Marginal Boarding and Alighting Times

Door crowding is the key variable in this study. Several measures, including load factors, that have been used in prior studies do not target the biggest issue in bus crowding—the congregation of crowds around the doors that creates an impedance for passengers boarding and alighting. Thus, this analysis creates new measures of crowding that can more effectively assess this important aspect. In this study, door crowding is discussed in terms of (1) the gross number of riders...
standing in the door areas and (2) the percentage of standing passengers who locate near doorways.

To assess performance, marginal passenger boarding and alighting times are used. In previous studies, it was common to separately assess marginal boarding times and marginal alighting times for buses. In Dhaka, however, the pushing and shoving that often characterizes the simultaneous boarding and alighting passengers requires a measure that captures the interaction between these two activities.

The combined marginal time for boarding and alighting passengers is calculated by considering only stops for which the buses came to a full stop for passengers to board and alight. The dwell time is calculated from the first board or alight after the wheels stop. In addition, because some buses dwell for many minutes to wait for additional passengers, only the first portion of the stop with the busiest activity was used. After 10 seconds of no boardings or alightings, the bus stop was considered “finished,” and the marginal boarding and alighting time was measured only for this initial period. Engineering judgment was used to choose this cutoff value and is acknowledged as a limitation to this study. The joint marginal boarding and alighting times is calculated by dividing the length of effective dwell time by the number of boarding and alighting passengers during the defined boarding and alighting period.

Elimination of Recording Errors

In the process of collecting the data, recording errors may have been introduced. These recording errors were identified by comparing the observed on-board number of BFR and FBD passengers to the number of standing passengers calculated from recorded boarding and alighting movements. The key assumption used in this comparison is that passengers desire to sit on the bus until there are no seats left available. This assumption is considered reasonable, as Bangladeshi passengers were observed to be aggressive in finding seats.

When the total number of BFR and FBD is greater than the number of standing passengers, it was assumed that a recording error had occurred because passengers could be standing outside the door areas in the aisles. To create a “cleaned” dataset that removed these recording errors, observations were deleted if they exceeded one of two error thresholds: (1) the difference between BFR + FBD and standing passengers was four passengers or more or (2) the difference was greater than 15 percent of the total number of passengers on the bus. Both of these thresholds were chosen through engineering judgment, because no established threshold
The impact of bus door crowding on operations and safety existed for cleaning the differences between observed and calculated passenger quantities. Application of these thresholds removed less than 4 percent of the 2,807 stops, leaving 2,703 bus stops in the “cleaned” dataset.

Analysis
The analysis is split into three parts that look at the various ways bus design affects crowding, and how the crowding then affects the service and safety of buses.

Bus Design and Crowding
Bus design factors, such as the presence of a front seating area, number and placement of doors, aisle length, and fare collection method (on-board or off-board payment), may influence how riders crowd within a bus. The relationships among bus design factors and the percentage of standing riders who crowd near doors is of particular interest, as this could result in longer dwell times and safety issues. That is, bus crowding near the doorways likely has a greater impact on operational performance and safety measures than crowding in the aisles because door crowding directly affects passengers attempting to board and alight.

In this section, door crowding as a percentage is examined as a function of the load factor of the bus right after it leaves a stop. Bus stops are defined as the unit of analysis, and all bus stops from the cleaned dataset are used. Defining crowding characteristics at the stop level, as opposed to a route level, allows examination of how crowding happens within the bus and how crowding relates to stop characteristics and dwell times.

The Transit Capacity and Quality of Service Manual (TCQSM) uses load factor to define different levels of service (LOS) within a transit vehicle (Kittelson & Associates 2003). Buses with standing passengers include LOS D (load factors between 1.0 and 1.25), LOS E (load factors between 1.26 and 1.5), and LOS F (load factors greater than 1.5). The TCQSM does not define LOS as a function of crowding around the doors, but the relationship between the two gives indication as to how different levels of crowding interact with bus design factors.

The existence of a front seating area near to the driver is associated with more riders standing near the front door when the bus is very crowded. A comparison between bus type 1 and bus type 2, identical except that bus type 1 has a front seating area, shows that the impact of a front seating area occurs when buses operate at LOS E and F. At these high levels of crowding, buses with a seating area
have a significantly greater proportion of stops in which the majority of standing passengers are near the door (59% vs. 29%). A Chi-square analysis provides further evidence of different door crowding levels when these buses operate at LOS E or F ($\chi^2 = 5.3 > \chi^2_{1,0.05} = 3.8$).

Two-door bus configurations vary in the physical location of their doors. Bus type 3 places doors at the front and middle of the bus, while bus type 4 has its rear door in the back of the bus. These different configurations result in distinct door crowding characteristics. Buses with front/middle designs have more crowding than buses with front/back designs. On average, 84 percent of standing passengers locate near doors on front/middle bus designs, compared to just 50 percent on buses with front/back designs. For the front/middle bus design, there are a large number of stops, with almost all standing passengers congregating near the door, even when load factors are high. A Chi-square analysis provides evidence that buses with front/middle door designs are associated with higher levels of door crowding ($\chi^2 = 20.0 > \chi^2_{1,0.00001} = 19.5$).

Aisle length also affects door crowding standing. A comparison is made between bus type 5 and bus type 1, similar except for their aisle length. It is seen that buses with shorter aisles are almost twice as likely to have the majority of standing passengers near the door when compared to buses with long aisles. A Chi-square analysis further confirms that short aisles are associated with a higher level of door crowding ($\chi^2 = 25.0 > \chi^2_{1,0.00001} = 19.5$).

Ticket (bus types 1–5) and local buses (bus types 6–7) both are prone to have standing riders congregating by doors. On average, 59 percent of standing passengers locate near doors on ticket buses compared to 66 percent on local buses. This average is significant at the 95% confidence level ($t = 3.32 > t_{1072,0.05} = 1.65$), but no clear differences emerged when different load factors were examined. Overall, local buses are crowded more often than ticket buses; however, when these buses are crowded, it appears that patrons on both ticket and local buses crowd in a similar fashion by the doorways.

Results indicate that doors are a popular place to crowd. Regardless of the crowding level on a bus, it is expected that approximately two-thirds of standees will wait near the door(s). Thus, even at low levels of crowding, doorway crowding occurs at a high rate. In turn, these high levels of door crowding can impact operational performance and safety measures, as discussed in the next sections.
Operational Performance and Crowding

Crowding around the doorways of a bus directly affects operations because passengers must push through a mass of people when boarding and alighting. In this part of the study, the gross number of passengers standing by the door is used to assess door crowding, measured at the stop level. One-door buses are analyzed statistically, whereas two-door buses (whose operations are affected by factors not recorded in the database) are described qualitatively.

In this section, BFR is adjusted to represent the effective BFR when the bus actually arrives at the stop (since BFR is noted immediately after the previous stop). This is determined by subtracting any alights (LA and EA) and adding any boards (LB and EB) between the two stops.

Increased crowding by the doorway results in longer joint marginal passenger boarding and alighting times. The crowding level near the doorway is stratified into three bins: no crowding (0 passengers before the front row [BFR]), low crowding (1–9 passengers BFR), and high crowding (10+ passengers BFR). As seen in Table 2, the mean marginal passenger boarding and alighting time increases approximately 25 percent across the three crowding levels, although it must be noted that the standard deviations are larger than the differences.

Table 2. Marginal Passenger Boarding and Alighting (B/A) Times for Different Levels of Door Crowding

<table>
<thead>
<tr>
<th>Crowding Level (BFR)</th>
<th>Mean B/A Time (sec)</th>
<th>Std. Dev. B/A Time (sec)</th>
<th>Count (# stops)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>2.33</td>
<td>1.15</td>
<td>515</td>
</tr>
<tr>
<td>1-9</td>
<td>2.54</td>
<td>1.33</td>
<td>466</td>
</tr>
<tr>
<td>10+</td>
<td>2.90</td>
<td>1.41</td>
<td>219</td>
</tr>
</tbody>
</table>

The distributions of these three levels of crowding are shown in Figure 3. Buses with more crowded doorway areas tend to have higher average marginal B/A times. A Chi-square analysis further confirms the differences in these distributions ($\chi^2 = 57.0 > \chi^2_{24,0.0005} = 53.4$).
Figure 3. Distribution curves of marginal boarding and alighting time at a stop for the three levels of crowding

Viewed by different levels of crowding by the door, as in Figure 4, the growth of marginal passenger boarding and alighting times increases nonlinearly as the number of passengers by the door increases. Although the standard deviation bars overlap with the uncrowded bus marginal time, the results provide a directional understanding of the relationship between door crowding levels and marginal boarding and alighting times.

To ensure that the results shown in Figure 4 were not influenced by the number of passengers boarding and alighting at a stop, the latter was used as a control variable. The gross combined level of boardings and alightings at a stop was used because it is consistent with the measure of a combined marginal dwell time defined earlier. The aim was to ensure that crowded buses were not dwelling longer per passenger due to the volume of operations occurring at the stop. Table 3 shows that for different levels of boarding and alighting at a stop, a more crowded bus takes longer per passenger. In addition, as the total number of boardings and alightings increases, the marginal boarding and alighting times decrease, which is consistent with prior findings reported in the literature (Guenther and Sinha 1983). Efficiencies are gained with more passenger movements at a stop.
Figure 4. Increase in marginal passenger boarding and alighting times as doorways get more crowded

Table 3. Relationship among Volume of Boardings and Alightings, Crowding Level, and Marginal Boarding and Alighting Times

<table>
<thead>
<tr>
<th>Boardings + Alightings</th>
<th>Crowding Level</th>
<th>Marginal Boarding and Alighting Times (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2–5</td>
<td>0</td>
<td>2.42</td>
</tr>
<tr>
<td></td>
<td>1–9</td>
<td>2.73</td>
</tr>
<tr>
<td></td>
<td>&gt;10</td>
<td>3.24</td>
</tr>
<tr>
<td>6–10</td>
<td>0</td>
<td>2.32</td>
</tr>
<tr>
<td></td>
<td>1–9</td>
<td>2.52</td>
</tr>
<tr>
<td></td>
<td>&gt;10</td>
<td>2.90</td>
</tr>
<tr>
<td>11–24</td>
<td>0</td>
<td>2.05</td>
</tr>
<tr>
<td></td>
<td>1–9</td>
<td>2.18</td>
</tr>
<tr>
<td></td>
<td>&gt;10</td>
<td>2.48</td>
</tr>
<tr>
<td>&gt;25</td>
<td>0</td>
<td>1.85</td>
</tr>
<tr>
<td></td>
<td>1–9</td>
<td>1.88</td>
</tr>
<tr>
<td></td>
<td>&gt;10</td>
<td>2.11</td>
</tr>
</tbody>
</table>
The results for one-door buses are clear, because all one-door buses operate with a single conductor and all passengers have to push through the same crowd at the front bus door to board and alight. Extending the analysis to two-door buses is much more complex because of their distinct designs and operations. For example, bus type 3 operates distinctly from other bus types because it has a middle door, and often the single conductor creates an internal flow with a front boarding and back alighting door. Similarly, even though bus types 4 and 6 both have front/back configurations, the latter has two conductors, which greatly influences how door crowding and curbside operations occur. Because of the interactions among conductors, bus designs, and internal flows, it was difficult to create robust relationships between bus crowding and boarding and alighting times for two-door buses (as the database did not record conductor behavior).

Linear Regression Models

Linear regression models were used to examine the combined impacts of the number of boardings and alightings, crowding measures, load factors, vehicle design characteristics, and fare payment type on marginal boarding and alighting times. Results for two models are shown in Table 4. Results show estimated changes in marginal dwell times for a marginal change in the respective variables. All variables are significant at the 0.05 level except LOS D in Model 2.

<table>
<thead>
<tr>
<th>Model 1</th>
<th>Model 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>2.450 (35.67)</td>
</tr>
<tr>
<td>LOS D</td>
<td>0.201 (2.41)</td>
</tr>
<tr>
<td>LOS E</td>
<td>0.345 (3.95)</td>
</tr>
<tr>
<td>LOS F</td>
<td>0.617 (6.57)</td>
</tr>
<tr>
<td>% of Standing Passengers by Door</td>
<td>--</td>
</tr>
<tr>
<td># of Boards and Alights</td>
<td>-0.029 (-7.40)</td>
</tr>
<tr>
<td>Ticket Bus</td>
<td>0.395 (4.45)</td>
</tr>
<tr>
<td>Large Bus</td>
<td>-0.331 (-3.83)</td>
</tr>
<tr>
<td>Adj. R²</td>
<td>0.060</td>
</tr>
</tbody>
</table>

Key: Parameter estimate (t-statistic). NOTE: LOS D is included to show non-linearity of increases in load factor from LOS D to LOS F, even though it is not always significant (as in Model 2).

Model 1 shows a linear regression using load factors, as represented through LOS dummy variables to describe how crowding affects marginal dwell time. The addi-
tion of a spatial crowding measure—the percentage of standing passengers located near doorways—improves the model fit. This is important because it shows that crowded buses can reduce their dwell times by conductors encouraging passengers to stand in the aisle. The boarding and alighting passengers regression coefficient indicates how each additional passenger reduces marginal dwell time.

Ticket buses have longer marginal dwell times than local buses, likely due to the need to collect tickets while boarding, but also the lower likelihood of passengers pushing and shoving when boarding the bus. The orderly boarding process adds to the bus’s dwell time. Among bus design characteristics examined (bus size, number of doors, front seating area, location of second door on two-door bus), only the variable for large vs. minibuses was significant. Large buses have shorter marginal dwell times because standing passengers have more room to spread out in the bus and do not need to stand by the door.

**Safety and Crowding**

Safety on buses focuses on several aspects. When crowded, riders often are forced to hang out of the door frame, wedging their foot onto the first step and grasping onto some piece of the bus. Buses often do not stop completely at a designated stop, choosing rather to roll through at a low speed to save time on their route. Passengers sometimes board and alight between stops, either when the bus is caught in the middle of traffic or when it is slowing down to make a turn. In this section, crowded buses are assessed to see if they influence these safety factors in a negative way. Crowded and uncrowded buses were compared using the cleaned dataset with all bus stops, except for the hanging out the door analysis. For examining passenger hanging out the door, only buses that have one or more passengers standing at the stop are used.

Crowding within a bus increases the possibility that passengers will hang out the door. Figure 5 shows the proportion of stops with passengers hanging out the door as well as the “conditional” average number of passengers hanging out the door. The latter is “conditional” in the sense that it includes only those stops for which at least one passenger is hanging out the door. As seen in Figure 5, higher load factors are associated with more passengers hanging out the door. In general, buses with load factors of LOS D and above do not have passengers hanging out the door. Two-door buses are more likely to have passengers hanging out the door (19.4% vs. 12.0%).
Figure 5 also displays the effect that load factors have on the number of people hanging out the door. As load factors increase, the frequency of stops with passengers hanging out the door increases. In addition, higher load factors are associated
with a greater average number of passengers hanging out the door. Two-door buses have larger averages because there are two doors at which passengers out the door are tallied.

There is a strong relationship between the number of passengers standing near the doorway of a bus and the number of passengers who are forced to hang out the door. For one-door buses, the correlation is 0.585, whereas for two-door buses the correlation is 0.708. Thus, as the number of riders standing near the doors increases, so does the number of passengers hanging out the door.

Buses that roll through a bus stop put passengers at risk by forcing them to jump and run when alighting or run and jump when boarding. Uncrowded buses are more likely to roll through a stop than crowded buses; 9.5 percent of uncrowded buses roll through bus stops as compared to 5.6 percent of crowded buses. A Chi-square analysis confirms this difference ($\chi^2 = 12.1 > \chi^2_{10.0005} = 12.1$). An alighting passenger is more at risk for a bus to roll through the passenger’s bus stop than a boarding passenger for both uncrowded and crowded buses.

Unsafe boardings and alightings occur between stops and, thus, put passengers at risk because other road users do not expect passengers to be boarding and alighting a bus at these locations. As seen in Table 5, crowded buses have higher rates of unsafe boardings and alightings. For different door crowding levels, it is seen that buses with higher volumes of crowding near the door have greater rates of early boards (EB), early alights (EA), late boards (LB), and late alights (LA). Significant to note is that the percentage of early and late boardings on crowded buses is nearly double those seen on uncrowded buses.

### Table 5. Percentage of Bus Stops at Different Door Crowding Levels that had Unsafe Boardings and Alightings

<table>
<thead>
<tr>
<th>Crowding (BFR and FBD)</th>
<th>EB (%)</th>
<th>EA (%)</th>
<th>LB (%)</th>
<th>LA (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>8.6</td>
<td>29.4</td>
<td>5.1</td>
<td>2.9</td>
</tr>
<tr>
<td>1–9</td>
<td>14.6</td>
<td>38.6</td>
<td>10.6</td>
<td>5.2</td>
</tr>
<tr>
<td>&gt;10</td>
<td>19.7</td>
<td>34.3</td>
<td>10.7</td>
<td>3.9</td>
</tr>
</tbody>
</table>

The phenomenon of crowded buses leading to greater rates of unsafe boardings and alights is likely due to conductors and drivers eager to raise revenue. Based on observations in the field, operators who aim to crowd their bus are also more likely to allow passengers to board between stops to garner additional ticket fares.
This creates the appearance that crowded buses have a greater likelihood of these operations, but the cause is more likely operators allowing this unsafe behavior. EB and LB have greater increases because operators are more likely to allow a potential rider to board between stops because it means more profit and less likely to allow a rider to alight between stops because it slows down operations and does not benefit their profit margin (the rider is already on board). In addition, it is less likely for an alighting passenger to push through a crowd at the door to alight between stops, whereas a potential boarding passenger does not perceive the crowded bus as an obstacle to boarding.

Buses in Dhaka are prone to stop farther than one lane from the curb and sometimes in the middle of the traffic stream, two to three lanes out. On average, uncrowded buses stop about half of the time within one lane of the curb, uncrowded buses slightly less often. The crowded buses’ slightly higher frequency of stopping farther than one lane from the curb, however, is not statistically significant. Thus, both crowded and uncrowded buses operate in an unsafe manner when stopping at a bus stop.

**Conclusion and Recommendations**

The results of the study are summarized in Table 6. The main contribution of the paper is that it is one of the first papers that quantifies the relationship between marginal dwell time and door crowding; to the authors’ knowledge, this is the first time this relationship has been explicitly quantified in the literature. This paper is also one of the first to show that certain bus design factors influence where passengers decide to stand—depending on aisle length, service type, the presence of front door seating, and the location of the back door on two-door buses, door crowding can be more prone to occur. Linear regression was used to show that this increased door crowding is a significant factor in increasing marginal dwell time. Through on-board observations, it was seen that door standing is preferred because it gives a passenger easy access to get off the bus; however, it causes the most issues for all other passengers.

This paper is also one of the first to explore the relationship between safety and crowding. We find some evidence that unsafe passenger behavior is amplified in crowded buses. Crowded buses increase passenger risk because crowding tends to occur most often at doorways. It is associated with unsafe boarding and alighting movements and passengers hanging out the door. Unsafe boardings increase
at a greater rate than unsafe alightings because it is more difficult to alight from a crowded bus than it is to board it, due to the need to push through a large crowd.

One interesting aspect of the results is that local buses, despite causing increased door crowding, have shorter marginal dwell times than ticket buses. This indicates that local bus passengers’ tendency to crowd the doorway is less of an issue in terms of dwell time than the need to process passengers carrying tickets. Thus, it is reasonable to conclude that service type has a larger role to play in affecting marginal dwell times than door crowding. Both service types, however, have increases in marginal dwell time when door crowding increases.

To reduce the negative effects of crowding, particular bus types could be operated. The optimal bus type would be a large two-door bus with a back door that does not have front seating, similar to bus type 4 in the study. This bus type is the least susceptible to the crowding that causes marginal dwell times to increase.

In addition to recommendations on bus design, we would offer that conductor training, while more difficult to implement, is also important. At low load factors, doorway crowding should be discouraged. In an environment like Bangladesh, where a conductor is always by the door, there should be an effort to train conductors and educate them on the dangers of crowding and how it affects passengers safety and operations. In any situation, door crowding should be discouraged, and an effort should be made to reduce the number of passengers by the door to improve performance.

<table>
<thead>
<tr>
<th>When the following factors exist/increase...</th>
<th>... they are associated with</th>
</tr>
</thead>
<tbody>
<tr>
<td>Front door seating</td>
<td>Increased door crowding</td>
</tr>
<tr>
<td>On two-door buses, middle door instead of back door</td>
<td>Increased door crowding</td>
</tr>
<tr>
<td>Aisle length</td>
<td>Decreased door crowding</td>
</tr>
<tr>
<td></td>
<td>Shorter marginal dwell time</td>
</tr>
<tr>
<td>Local bus service</td>
<td>Increased door crowding</td>
</tr>
<tr>
<td></td>
<td>Shorter marginal dwell time</td>
</tr>
<tr>
<td>Door crowding</td>
<td>Longer marginal dwell time</td>
</tr>
<tr>
<td></td>
<td>Riders hanging out the door</td>
</tr>
<tr>
<td></td>
<td>Increased unsafe boarding and alighting</td>
</tr>
<tr>
<td></td>
<td>Increased likelihood of stopping</td>
</tr>
</tbody>
</table>
Conductors play a large role in keeping people from engaging in unsafe behavior. First, they can tell how crowded the bus is, and they have the power to prevent people from boarding a bus that is crowded. The conductor can help actively discourage people from hanging out the doors. It is recommended that conductors be made aware of the dangers of hanging out the door and monitor all doors carefully. The risks of EA, LA, EB, and LB must also be brought to conductors’ attention, and there should be efforts made to discourage conductors from picking up or dropping off passengers mid-route. Crowded buses are associated with more EB and LB, which may be due to conductors who are consciously trying to crowd buses and are actively seeking to pick up people between stops.

Reducing door crowding, unsafe boarding and alighting, and rolling through stops could be furthered through police enforcement. In Dhaka, bus operators already can be cited for using buses over a certain age and for improper fare pricing. Citing operators for visible violations of safe practices could increase the likelihood that the proposed conductor training is successful. It is expected that a conductor’s knowledge of the negative effects of crowding are not enough to forgo crowding in order to maximize profit. In the areas that can be directly controlled, such as not allowing passengers to hang out the door, not rolling through stops, and preventing boarding and alighting when moving, monetary penalties could be implemented. If implemented, future research could measure the effect that training and enforcement have on door crowding.

The increase in dwell time caused by crowding is important for a transit operator to consider. Crowding on buses may be necessary in a system constrained by traffic congestion, but it must be recognized that crowding the door areas increases the operating time for a transit vehicle and creates unsafe situations for riders.

Acknowledgments

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The Impact of Bus Door Crowding on Operations and Safety

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Modeling Commuter Preferences for the Proposed Bus Rapid Transit in Dar-es-Salaam

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University of Twente, The Netherlands

Abstract

The paper analyzes individual commuter preferences towards the proposed bus rapid transit (BRT) system in Dar-es-Salaam, Tanzania. The objective of the survey was to identify how commuters perceive and value the proposed BRT service quality attributes. A stated preference survey of potential users of the proposed BRT was administered to 684 commuters who traveled to the central business district (CBD) on a regular basis. To this end, a special pictorial score card was developed that was suited for the local context and needed to capture the preferences of the commuter respondents. The BRT attributes considered for study are travel time, travel fare, and comfort. The stated choice data were analyzed using a binary logit model. The findings reveal, in order of importance, that comfort is the most valued attribute compared to travel time and travel fare, respectively.

Introduction

In the city of Dar-es-Salaam, Tanzania, as elsewhere in developing countries, concerns over urban growth and its transport implications are becoming more important in both the national and local political agendas. This is particularly true in the city where increasingly new peripheral developments have resulted to increased
congestion and placed stress upon the local transport networks and the urban environment (World Bank and OECD. 2003). Dar-es-Salaam is one of the fastest-growing cities in Sub-Saharan Africa, with an estimated urban population of almost 4 million inhabitants in 2010 and annual population growth rate of more than 4 percent per annum (JICA 2007). The city is characterized by a high proportion of informal development and poverty where nearly 70 percent of its population lives in informal settlements (World Bank 2002). Most people cannot afford a private car, and around 75 percent of trips in Dar-es-Salaam are made by public transport and walking (Olvera et al. 2003; Nkurunziza et al. 2012).

Like many other rapidly-growing cities in Sub-Saharan Africa, Dar-es-Salaam has not escaped from the impacts of poor public transport services: inefficiency, poor quality of service, and lack of safety for commuters. The main factors leading to these include rapid expansion of the city, which has far outpaced the capacity to provide basic infrastructure and services; the poor state of a majority of the buses; untrained bus drivers and conductors who are driven by the pursuit of daily revenue targets payable to bus owners; non-adherence to traffic rules and regulations; and lack of an organized public transport system (Kanyama et al. 2004; Nkurunziza et al. 2012). The city public transport service is mainly dominated by small buses—Daladalas—with capacities ranging from 16 to 35 passengers. The actual fare level of a Daladala is between 250 and 350 Tshs (Tanzania Shillings; 1 US$ = approx. 1,200 Tshs, at time of survey), independent of the travel distance. The current public transport system has great difficulty in coping with the demographic and spatial growth of the city and in meeting the basic needs of its inhabitants (Sohail et al. 2004). Access to affordable and good quality public transport services is critical for the urban population, as a lack thereof leads to economic, social, and physical isolation (Department for International Development 1999), especially low-income communities located in the city outskirts with inadequate access to public transport and other basic urban facilities (Hine 2003; Olvera et al. 2003).

In response to the public transport challenges in Dar-es Salaam, an urban development strategy was designed and proposed to introduce a bus rapid transit system (BRT) for the entire city (ITDP 2005). BRT has emerged as an economical transit alternative with significant potential for developing countries (Wright 2002). Today, the BRT concept is becoming increasingly implemented by cities looking for cost-effective transit solutions. The proposed BRT system, branded Dar-es-Salaam Rapid Transit (DART), will operate on specially-designated infrastructure and is planned to replace the current inefficient and unpredictable Daladalas on the main
corridors. DART will be implemented in six phases, with the construction of the first phase in 2010. Once the current plans are implemented, the total corridor length will be more than 130 kilometers, with a long-term plan of covering the whole city by the year 2035. The DART Agency will be the public regulatory authority managing the DART system to ensure quality control and will be responsible for policy-setting, regulation, planning, and controlling of operations and marketing of the system (JICA 2007). The DART project seeks to provide a high-quality, affordable mobility service that improves both the environment and the quality of life of the city’s residents.

Although the BRT is aimed to enhance and improve the quality of service to regain passenger confidence in public transport, the critical challenge remains regulating and controlling cost minimization pressure of the profit-seeking private sector, which currently dominates public transport service provision, without sacrificing the quality of service offered (Sohail et al. 2004). The main objective of this paper is to analyze commuter preferences towards the proposed BRT system in Dar-es-Salaam and explore user perceptions of its service quality attributes.

Overview of Earlier Studies and Approaches
The need to improve the quality of public transit services to meet the ever-increasing needs and expectations of passengers has been one of the main desires of urban transport planners worldwide (Mfinanga and Ochieng 2006; Ji and Gao 2010; Currie and Delbosc 2011). For each individual journey, people have the choice between different travel modes, each with specific characteristics, advantages, and disadvantages (Garling 2005). In other words, public transport competes with other modes and will be used only if it can meet the expectations of the traveling public, that is, if it can deliver an attractive, accessible, reliable, affordable, and safer service (Stradling et al. 2007; Currie, 2005). A thorough understanding of user perceptions of the quality of service provided by the system is, therefore, a prerequisite to realization of the above ambition.

A review of the international literature on public transit quality shows that quality of service in public transit reflects passenger perception of transit performance (Currie and Wallis 2008; Hensher et al. 2003). The concept of service quality has been extensively applied to public transit systems and may be defined as customer perception of how well a service meets or exceeds their expectations (Geetika and Nandan 2010). Service quality can be measured in terms of customer percep-
tion, customer expectation, customer satisfaction, and customer attitude. It covers many diverse topics, such as comfort outside and inside the vehicle, journey times, convenience of service, and existence of supporting infrastructure (Litman 2008; Currie 2005). The overall process to improve public transit service quality entails identification of customer priorities and needs, measurement of customer satisfaction using appropriate indices, use of this feedback to evaluate relevant service parameters, and, finally, the definition and implementation of measures to improve the services provided to customers. Research has revealed that the quality of each of the public transit service attributes is related to the importance each individual commuter places on it (Dell’Olio et al. 2010; Foote et al. 2001).

Much effort has been made by various studies on urban public transit services; for example, a number of approaches and techniques such as customer loyalty and benchmarks have been used to define, assess, and evaluate quality of service. These approaches have been addressed at different levels of significance in various countries, primarily in the developed world (Foote et al. 2001; Morpace International, Inc. 1999; Kittelson & Associates et al. 2003). Some studies have focused on the assessment of public transport level of service (Mfinanga and Ochieng 2006; Too and Earl 2010), while others evaluate public transit service quality from the perspective of user satisfaction. For example Ji and Gao (2010) identified significant factors of satisfaction from the analysis of people’s satisfaction with public transportation as well as accessibility factors and personal attributes with a multi-level logistic regression model. Dell’Olio et al. (2010) used ordered probit models to evaluate how bus users perceive the quality of their public transit service. Stradling (2007) characterized the dimensions of bus service acceptability by examining what bus users disliked and liked about traveling by bus in Edinburgh using factor analysis. Tyrinopoulos and Antoniou (2008) combined factor analysis and ordered logit modeling to assess the quality implications of the variability of user perceived satisfaction across public transit systems. Too and Earl (2010) developed and used a SERVQUAL framework to measure public transport services. Their findings revealed a wide gap between community expectations of public transport services and the actual service quality provided. Eboli and Mazzulla (2008) conducted a stated preference experiment to identify the importance of service quality attributes on global customer satisfaction and calculated a service quality index that provides an operationally-appealing measure of current or potential service effectiveness.
Although there is much work on public transit quality, based on the authors’ knowledge, the study of this topic in Sub-Sahara African cities, and Dar-es-Salaam in particular, using a similar approach is very rare, indeed perhaps not available at all. Knowledge of how people value the quality of a public transit service would benefit transport planners, policy makers, and public transit operators to stipulate strategies of service quality improvement. This would help to design service quality interventions that meet customer expectations while eliminating subjectivity in the decision making of urban policies. This paper aims to address this gap in knowledge and reports the results of a stated preference survey conducted in the city of Dar-es-Salaam.

Methods and Materials

Survey Design and Data Collection Procedure

A stated preference (SP) survey was conducted in September 2007 among individual regular commuters in the city of Dar-es-Salaam who traveled to the CBD for main daily activities. The objective of the survey was to collect stated choice data to analyze commuter preferences towards the proposed BRT quality of service. Given that the BRT system was not yet in place at the time of the survey, the study was conducted to only daily commuters who were assumed to be an appropriate target group with the potential of using and affording the BRT system service.

The survey samples were collected from pre-selected zones of the city based on three criteria: 1) whether the residential zones are densely populated and located in areas around the proposed BRT corridors, 2) whether the residential zones are planned or unplanned, in order to capture views from different categories of people, and 3) the residential zone location distance from the CBD. Based on these criteria, the selection of the survey zones was done with assistance from group discussions held with local experts from DART, the Dar-es-Salaam City Council, Ardhi University, the University of Dar-es-Salaam, and the JICA team that was conducting the city transport master plan study. Individuals were approached in their homes (within the pre-selected zones) in the evenings after they had returned from their daily activities. This was done purposely to allow for more time for the respondents to develop their answers in a relaxed atmosphere for the choice questions. The homes were visited randomly with the help of local leaders in a given residential area. The study employed the concentric zonal survey approach, which is sampling respondents in reference to distance from CBD (Goudie 2002). A CBD is a major trip attraction zone of a city and, for the case of Dar-es-Salaam, the CBD accom-
modates most of the public and private activities and is a major destination of most of the commuting trips in the city. The city was divided into four ring buffers based on the radial distance from CBD, with the CBD as a reference point. The four ring buffers created were zones within 5km from the CBD, zones 5–10 km from the CBD, zones 10–15 km from the CBD, and zones beyond 15km from the CBD. It was decided to work with categories of commuters (potential users) defined by radial distance from the CBD with an aim to reveal whether the residential location distance from the CBD has an influence on the commuter choice of the proposed BRT service.

The survey questionnaire used was composed of three main parts. The first part collected information related to individual travel behavior, which was used to customize the second part and gave an overview of the sample travel characteristics. The second part was strictly stated choice questions (i.e., a series of binary bus choices). The third part was meant to collect socio-economic and demographic information of the sample. A total of 740 commuter respondents were interviewed from different residential zones within the four different ring buffers, resulting in 684 completed questionnaires, a response rate of 92 percent. The high response rate is attributed to the methods employed and the mini-pilot survey done prior the main survey data collection. As each respondent made nine choices from the nine scenarios, the potential total number of observations (pseudo-individuals) was 6,156, a reasonable sample size for choice modeling. Earlier studies show that the ideal number of respondents required per design treatment is between 30 and 50 individuals (Ahern and Tapley 2008; Hensher 1994). Normally, 500 to 1,000 sample observations are more than adequate to give better estimations (Louviere et al. 2000). Because of the focus on commuters, the respondents interviewed were ages 15 years and above.

**Stated Choice Design**

The SP approach has been widely used in transportation, given its potential to measure how people choose not-yet-existing travel modes or how people take actions in case of introducing new policies—for example, in this case with the introduction of a new bus transit system (Hensher 1994). As people in Dar-es-Salaam have not experienced the proposed BRT system, it is not reliable to use only data about actual travel behavior to represent people’s future preferences; it is necessary to use a stated preference approach, which has the ability to measure responses under not-yet-existing conditions (Louviere et al. 2000). SP questions were designed to reveal the alternatives that individual commuters say they would
choose in a given hypothetical situation. Each alternative is assigned a certain combination of attributes, and the individual chooses the alternative he/she finds has the most appealing combination of attributes.

**Definition of the BRT Attribute Variables**

The attributes used in the choice experiment are based on the proposed BRT service quality features obtained from the BRT system design reports of Logit (2007) from DART and the Dar-es-Salaam City Council. The three attributes were travel time, travel fare, and comfort. Travel time (one way) in this study is defined as the sum of access (walking) time to BRT stop, waiting time at BRT stop, and in-bus travel time taken to reach the CBD. Travel fare (one way) is defined as a fee charge of using the BRT to reach the CBD. DART will operate according to a flat fare system and, thus, respondents were presented the same travel fare. According to the BRT Investors documents, the travel fare for the BRT one way would be 500 Tshs, and this was the fare considered in this study. Comfort in this study was defined as the in-bus comfort during the trip to CBD. The comfort attribute was measured at three levels: 1) comfortable seating—the commuter can sit during the complete journey; 2) comfortable standing—the commuter can only stand during the trip but the standing conditions are considered comfortable if the commuter can easily move his arms and legs and can easily leave the bus without the need to ask other people to give space; and 3) overcrowded standing—the commuter has no seat available during the trip but, in this case, the standing conditions are worse than comfortable standing; walking through the bus is almost impossible, and, thus, the respondent can roughly make a comparison with the situation of an overcrowded Daladala.

The three attributes were selected among others based on input obtained through work sessions with local experts from DART, the Dar-es-Salaam City Council, and Ardhi University, which also helped to individualize the most relevant attribute levels. Comfort was also considered in this study because other studies in Dar-es-Salaam have shown that people value comfort highly (Kanyama et al. 2004). The attributes and their levels were later validated based on input from a mini-pilot survey among daily commuters. Hensher et al. (2005) suggests that three attributes with three levels are enough to provide knowledge of a good approximation of the true underlying utility function. The attributes were varied over three levels. Table 1 describes the BRT attribute variables used in the study.
Table 1. Description of BRT Attribute Variables

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Level values</th>
<th>Unit</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Travel time</td>
<td>0–5km: 15, 30, 45 5–10km: 20, 40, 60 10–15km: 30, 55, 80 &gt;15 km: 45, 75, 105</td>
<td>Minutes</td>
<td>Total BRT travel time to CBD (walk time to BRT stop + wait time at BRT stop + in-vehicle travel time) (one way)</td>
</tr>
<tr>
<td>Travel fare</td>
<td>300, 500, 700</td>
<td>Tshs*</td>
<td>Total BRT travel fare to CBD (one way)</td>
</tr>
<tr>
<td>Comfort</td>
<td>1 = seat guaranteed 0 = comfortable standing -1 = overcrowded standing</td>
<td>Level of comfort</td>
<td>Comfort level when inside the bus</td>
</tr>
</tbody>
</table>

*Tshs = Tanzania Shillings, 1 US$ = approx. 1,200 Tshs as of September 2007

For the attribute level values to be realistic for the study context and acceptable to respondents, the maximum and minimum attribute level values for the experiment were set close to the attribute level values of a Daladala and realistic for the BRT system. The attribute levels were tested through a pilot survey with 20 individual Daladala regular commuters. This enabled us to increase the realism of the hypothetical choice context to a plausible maximum by bridging the gap between reality and stated intentions. The pilot survey also enabled us to validate the questionnaire and verify the existence of trade-offs in the evaluation of attributes and the lack of dominant or lexicographic behavior among respondents.

The stated preference scenarios for this survey were constructed using a fractional factorial design. To produce a fractional factorial, traditional orthogonal design in statistical package, SPSS was used. The method of producing factorial design in SPSS is described in Hensher et al. (2005). The full factorial allowing estimating main effects requires defining 27 choice scenarios. However, submitting respondents to such a burden runs the risk of losing their attention and obtaining inconsistent answers (Iragüen and de Dios Ortúzar 2004). For these reasons, a fractional factorial was used to reduce the number of scenarios from 27 to 9.

For the purpose of this study, respondents were asked to choose between two unlabeled bus alternatives—Bus A or Bus B. Unlabeled choice scenarios were presented to respondents to avoid bias that could be brought by the attached label "BRT" when making a choice. In Dar-es-Salaam, where most people have a low literacy level, it was necessary to present choice scenarios in a way that could be interpreted easily and homogeneously to achieve better utility estimations. Carson et al. (1994) recommended the use of graphic representations as an aid for respondents, and this was emphasized in recent SP studies (Iragüen and de Dios Ortúzar 2004; Tilahun et al. 2007). To make sure that every individual respondent interprets
homogeneously the same bus quality attributes in all choice scenarios, especially for the qualitative attributes such as comfort, where different interpretations from respondents were possible, a combined pictorial and verbal format was presented and elaborately tested at the SP exercise. Figure 1 is an example of one of the nine stated preference scenarios presented in the survey. (A copy of the nine SP survey choice sets can be available from the author upon request.)

Model Structure and Explanatory Variable Specification

The stated choice data from the SP survey was analyzed using a random utility model. This is, by far, the most-used model for processing data from choice experiments in transportation research (Ben-Akiva and Lerman 1985; Louviere et al. 2000). The model assumes that travel decision makers face a utility maximization problem based on the cost and quality of service stemming from using a given mode and the uncertainty of choosing the given mode (Ortúzar and Willumsen 1994). This study uses a random utility model in the form of binary logit. The maximum likelihood method was used to estimate the binary logit models. The stated choice data was modeled using Bierlaire’s optimization toolbox for general
extreme value model estimation (BIOGEME) version 1.5 (Bierlaire 2003). The specified random utility model estimated for this study is expressed as:

\[ U_{bn} = V_{bn} + \varepsilon_{bn} \]  

Where, \( n \) is an index for individuals; \( b \) is an index for bus (BRT) - (\( b = A \) or \( B \), because each scenario comprises two alternative buses); \( U_{bn} \) is the utility of the bus rapid transit (BRT/DART) by an individual \( n \); \( V_{bn} \) is the systematic utility component of the BRT; and the random error term \( \varepsilon_{bn} \) is the non-observable utility component of the BRT, which is assumed to be identically and independently standard Gumbel distributed across alternatives and observations. The systematic part of utility depends on the attributes considered in the study and, in this case, is given by the equation

\[ V_{bn} = \sum \beta_{bk} X_{bkn} \]

Where, \( V_{bn} \) is the systematic utility component of the BRT; \( \beta_{bk} \) is the utility coefficient associated with attribute \( X_{bkn} \) of the BRT; \( X_{bkn} \) represents a vector of explanatory variables specific to BRT \( b \) and individual \( n \); and \( k = \) the \( k^{th} \) attribute of the BRT. The systematic utility functions of the alternatives are linear combinations of the bus service quality attributes, as shown in the following expression:

\[ V_{brt \_bi} = \beta_{tt \_bi} TT_{brt} + \beta_{fare \_bi} FARE_{brt} + \beta_{cft \_bi} CFT_{brt} \]  

Where, \( V_{brt \_bi} \) = systematic utility component of BRT per buffer ring; \( TT_{brt} \) = total travel time of BRT (one way); \( FARE_{brt} \) = total travel fare of BRT (One way); \( CFT_{brt} \) = comfort of the BRT; \( \beta_{tt \_bi} \) = coefficient associated with attribute travel time, specific for each buffer ring; \( \beta_{fare \_bi} \) = coefficient associated with attribute travel fare, specific for each buffer ring; \( \beta_{cft \_bi} \) = coefficient associated with attribute comfort, specific for each buffer ring; and \( b_i \) = buffer ring \( i \) where \( i = 0–5 \text{km}; 5–10 \text{km}; 10–15 \text{km}; \text{and } >15 \text{km}. \)

As this was an unlabeled design, the intercept has not been considered when designing the models, and no socio-economic variables have been introduced (Hensher et al. 2005). For a more detailed discussion on stated preference surveys, see Polak and Jones 1997; Rose and Bliemer 2009; Rose et al. 2008; and Hensher et al. 2005. For more detailed discussion on discrete choice modeling, see Ben-Akiva and Lerman 1985; Louviere et al. 2000; and Ortúzar and Willumsen, 1994.
Results and Discussion

Descriptive Statistical Analysis

The descriptive analysis results of the survey data (see Table 2) show relatively good representation of male and female respondents, and the comparison between the sampled population and the Dar-es-Salaam population indicates a relatively good representative sample. The employment status of the sampled population shows that all groups were represented. However, the self-employed are over-represented because, unlike the city population at large, most commuters to downtown are self-employed businessmen and petty traders.

Table 2. Socio-Demographic Profile of Sample Respondents

<table>
<thead>
<tr>
<th>Factor</th>
<th>% Sample Respondents</th>
<th>% Dar-es-Salaam Population</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>53.7</td>
<td>50.5</td>
</tr>
<tr>
<td>Female</td>
<td>46.3</td>
<td>49.6</td>
</tr>
<tr>
<td>Age Group*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15–25 years</td>
<td>30.3</td>
<td>36.5</td>
</tr>
<tr>
<td>26–64 years</td>
<td>68.1</td>
<td>60.4</td>
</tr>
<tr>
<td>&gt;64 years</td>
<td>1.6</td>
<td>3.1</td>
</tr>
<tr>
<td>Employment Status**</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Full-time</td>
<td>21.2</td>
<td>22.1</td>
</tr>
<tr>
<td>Part-time</td>
<td>12.9</td>
<td>N/A</td>
</tr>
<tr>
<td>Self-employed</td>
<td>44.7</td>
<td>22.8</td>
</tr>
<tr>
<td>Student</td>
<td>11.8</td>
<td>11.5</td>
</tr>
<tr>
<td>Other</td>
<td>9.4</td>
<td></td>
</tr>
<tr>
<td>Education Level**</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No education</td>
<td>1.3</td>
<td>7.6</td>
</tr>
<tr>
<td>Primary</td>
<td>32.3</td>
<td>60.6</td>
</tr>
<tr>
<td>Secondary school</td>
<td>44.9</td>
<td>1.7</td>
</tr>
<tr>
<td>Higher</td>
<td>21.2</td>
<td>2.9</td>
</tr>
<tr>
<td>Missing data</td>
<td>0.3</td>
<td></td>
</tr>
</tbody>
</table>

*Source: Population & Housing Census 2002
** Source: Source: Household Budget Survey 2000/01

Most respondents were between 26 and 64 years of age, as expected, since this is the working-age group, which indicates good data in the point of view of this
research. A higher percentage of the sampled respondents had completed their secondary-level education compared to the city population. This difference is reasonable since one would expect daily commuters to have a higher education level.

Table 3 shows that most commuters travel to CBD for business (large-scale business, petty trading, business shopping) activities. Those who travel to the CBD for office work activities i.e., government and private institutions, constitute about 29 percent, school trips about 10 percent, and remaining others 13 percent. The modal share of the sample shows that 88 percent of commuters use public transport (Daladala), 8.9 percent private car, 1.8 percent walk, 0.3 percent bicycle, and 1.1 percent other modes.

### Table 3. Travel Behavior of Sample Respondents

<table>
<thead>
<tr>
<th>Factor</th>
<th>% Sample Respondents</th>
<th>% Dar-es-Salaam Population</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main trip purpose to CBD</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Work</td>
<td>28.5</td>
<td>N/A</td>
</tr>
<tr>
<td>School</td>
<td>9.5</td>
<td>N/A</td>
</tr>
<tr>
<td>Business</td>
<td>49.0</td>
<td>N/A</td>
</tr>
<tr>
<td>Other</td>
<td>12.9</td>
<td>N/A</td>
</tr>
<tr>
<td>Missing data</td>
<td>0.1</td>
<td>N/A</td>
</tr>
<tr>
<td>Main mode of travel</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Daladala (public transport)</td>
<td>87.9</td>
<td>42.0*</td>
</tr>
<tr>
<td>Bicycle</td>
<td>0.3</td>
<td>3.0*</td>
</tr>
<tr>
<td>Walking</td>
<td>1.8</td>
<td>46.0*</td>
</tr>
<tr>
<td>Private car</td>
<td>8.9</td>
<td>9.0*</td>
</tr>
<tr>
<td>Other</td>
<td>1.1</td>
<td>N/A</td>
</tr>
</tbody>
</table>

* Source: Amer et al. 2007

N/A = data not available

### Model Results

Results from all models have shown that the parameter on travel time variable is negative and highly significant, reflecting a preference for shorter travel times. The parameter on the travel fare variable is negative and shows a significant aversion to expensive travel fares. The comfort parameter has a positive sign, as expected, and significantly indicates that commuters prefer traveling in a comfortable environment.
To examine the relative importance of the attributes, willingness to pay (WTP) values were estimated. These estimates examine the value attached to each of the attributes by respondents in different locations of the city. The WTP value for travel time attribute of the BRT is the marginal rate of substitution between travel time and travel fare and is given by the ratio of the travel time utility parameter and the travel fare utility parameter. Likewise, the WTP value for comfort is given by the ratio of comfort utility parameter and the fare utility parameter (Louviere et al. 2000). The results shown in Table 4 suggest that a sampled individual is willing to pay, on average, 30.2 Tshs to save 1 minute of time spent traveling to the CBD, holding other factors constant. In the same way, a sampled individual is willing to pay 343 Tshs to gain a unit level of in-bus comfort. The results again show that, on average, a sampled individual is willing to pay 11.4 times more to gain a unit level of in-bus comfort than to save a unit of travel time.

Table 4. Overall Model Based on Total Sample

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Coef.</th>
<th>WTP</th>
<th>t - test</th>
<th>p - value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Travel Time</td>
<td>-0.0487</td>
<td>30.2</td>
<td>-17.75</td>
<td>.000</td>
</tr>
<tr>
<td>Travel Fare</td>
<td>-0.00161</td>
<td>-5.16</td>
<td>.000</td>
<td></td>
</tr>
<tr>
<td>Comfort</td>
<td>0.552</td>
<td>343</td>
<td>10.38</td>
<td>.000</td>
</tr>
<tr>
<td>No. of estimated parameters</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No. of observations</td>
<td>6,156</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Init. log-likelihood</td>
<td>-4266.321</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Final log-likelihood</td>
<td>-2652.603</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Likelihood ratio test</td>
<td>3227.436</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rho-square</td>
<td>0.378</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Tables 5 and 6 show results from models depending on distance from CBD. A sampled individual is willing to pay, on average, 18.3 Tshs, 4.2 Tshs, 5.5 Tshs, and 8.6 Tshs to save 1 minute of time spent traveling to the CBD *ceteris paribus* when from within 5km, 10km, 15km, and beyond 15 km distance from the CBD, respectively. Likewise, on average, holding other factors constant, a sampled individual is willing to pay 745 Tshs, 360 Tshs, 291Tshs, and 282 Tshs to gain 1 unit level of comfort from within 5km, 10km, 15km, and beyond 15 km distance from the CBD, respectively. The results also reveal that a sampled individual is willing to pay, on average, 40.7, 86, 52.9, and 33 times more to gain 1 unit level of comfort than to save 1 unit of travel time when from within 5km, 10km, 15km, and beyond 15 km distance from
the CBD, respectively. The model results, in all cases, clearly indicate that the value attached to comfort (in-bus during travel) is higher than that of travel time, simply suggesting that an individual commuter would be willing to pay more to gain a unit level of comfort (in-bus) than to save a unit of travel time holding other factors constant. For example, considering the overall model results (Table 4), an individual commuter from any zone in the study area is willing to pay, on average, 11.4 times more to gain a unit level of comfort than to save a unit of travel time.

Table 5. Models Depending on Radial Distance from CBD

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Coef.</th>
<th>WTP</th>
<th>t - test</th>
<th>p - value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Travel Time</td>
<td>-0.0272</td>
<td>18.3</td>
<td>3.23</td>
<td>.000</td>
</tr>
<tr>
<td>Travel Fare</td>
<td>-0.00149</td>
<td>-2.01</td>
<td>.040</td>
<td>-0.00353</td>
</tr>
<tr>
<td>Comfort</td>
<td>1.11</td>
<td>745</td>
<td>8.26</td>
<td>.000</td>
</tr>
<tr>
<td>No. of estimated parameters</td>
<td>3</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No. of observations</td>
<td>610</td>
<td>1,341</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Init. log-likelihood</td>
<td>-422.127</td>
<td>-923.272</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Final log-likelihood</td>
<td>-352.817</td>
<td>-799.266</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Likelihood ratio test</td>
<td>138.618</td>
<td>248.012</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rho-square</td>
<td>0.164</td>
<td>0.134</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 6. Models Depending on Radial Distance from CBD

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Coef.</th>
<th>WTP</th>
<th>t - test</th>
<th>p - value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Travel Time</td>
<td>-0.0343</td>
<td>5.5</td>
<td>-3.06</td>
<td>.000</td>
</tr>
<tr>
<td>Travel Fare</td>
<td>-0.00623</td>
<td>-3.40</td>
<td>.000</td>
<td>-0.00405</td>
</tr>
<tr>
<td>Comfort</td>
<td>1.81</td>
<td>291</td>
<td>5.66</td>
<td>.000</td>
</tr>
<tr>
<td>No. of estimated parameters</td>
<td>3</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No. of observations</td>
<td>272</td>
<td>504</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Init. log-likelihood</td>
<td>-188.536</td>
<td>-349.346</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Final log-likelihood</td>
<td>-153.549</td>
<td>-302.459</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Likelihood ratio test</td>
<td>69.975</td>
<td>93.774</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rho-Square</td>
<td>0.186</td>
<td>0.134</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
While the willingness to pay values of the attributes differed in the different models, results from all models show that comfort is more valued than travel time and travel fare, revealing its importance to the proposed BRT service quality. Although comfort is more valued than travel time and travel fare from all model results, the value placed on comfort decreased as residential location distance from the CBD increased. People located in zones close to the CBD attach more value to comfort, and this value decreases as one moves away from the CBD. The possible explanation for this may be that people who mainly live in the city peripherals are the poor and, for these people, comfort would be reasonably less valued compared to those who live closer to CBD. Similarly, comfort and travel time are valued higher by commuters from zones close to CBD (i.e., within 5 km to the CBD) than those from city peripherals. It was, however, expected that commuters from zones located far from the CBD would highly value travel time and comfort since they have to travel longer. The reason could be that people who live close to the CBD are mainly government workers who are highly-educated and business men who have relatively high incomes and, from their point of view, value time as money and comfort as high-class.

On the other hand, although travel fare proved very significant, it was unexpectedly less valued than other attributes. It was, however, expected that people would value travel fare more than comfort and travel time given that the Dar-es-Salaam population is mainly low income. There are two possible explanations: 1) since most commuters usually have to make one or more Daladala transfers currently from their residential locations to reach the CBD and each time a transfer is made the travel fare doubles (the Daladala fare ranged from 250 to 500 Tshs for one-way travel at the time of the survey), the BRT travel fare (expected to charge a flat fare of 500 Tshs one way) may be seen less expensive to commuters than the Daladala fare charge; 2) given the poor service and traveling environment of the Daladalas, characterized by uncomfortable, unsafe, and overcrowded conditions, a high preference for comfort over travel fare seems reasonable and unsurprising.

**Policy Implications**

The study results indicate that when asked to rank the importance of three variables related to future BRT, commuters in Dar-es-Salaam overall placed a premium on comfort followed by faster travel times and lower fares. There was some variation based on how far the respondents lived from the CBD. Respondents who lived closest to the CBD placed a premium on comfort (in-bus), while respondents who lived on the periphery of the CBD placed a premium on lower fares.
Moreover, it was possible to extract spatial variation in preferences for the proposed BRT service attributes among the potential users. Such an understanding can be incorporated into the planning process to help planners to make better recommendations and operators to make appropriate investment decisions in order to provide a public transit service that is more appealing to the public.

The high significance of the in-bus comfort, travel time and travel fare attributes in modal choice decision making of a commuter suggests that the DART Agency would pay more attention and consider these attributes important when providing the BRT service. However, when implementing the BRT, priority and particular attention should be given to the order of importance of the attributes for effective delivery of high-quality public transit service.

Although results have generally shown that the travel fare attribute is less important compared to comfort and travel time, planners and decision makers should handle it carefully given its high significance and also given that Dar-es-Salaam’s population is dominated by low-income earners. Only through providing transport services characterized by better comfort, lower travel times, and lower travel fares will the proposed BRT be sustainable and attractive to its potential users.

**Conclusion**

This study attempted to evaluate the proposed BRT service quality through analysis of commuter stated preferences. In most developing countries, population preferences are hardly taken into account by planners and policy makers, consequently not meeting the desires of the society in question. The stated preference approach and the logit model used in this study can be used to integrate the views of society in planning, especially in evaluating new public transit services or changing existing ones. This gives logit models a very strong policy role by assisting analysts, researchers, and planners in evaluating the impact of many policies as defined by specific mixes of attributes modeled in utility expressions.

A stated preference survey instrument was developed in which people had to make choices among two hypothetical bus alternatives. The results generally revealed that commuters are willing to pay the highest price for traveling in a more comfortable environment, followed by lower travel times and paying lower travel fares. However, the results further highlight the differences in valuation of the attributes based on spatial location of the sampled population in the city. A higher preference is indicated for in-bus comfort by commuters from zones close to the CBD, while
commuters from the city peripheral zones seemed to have a higher preference for travel fare and appeared less willing to pay for comfort than those from the inner zones of the city. These findings are in line with the statement that people value the characteristics of goods, not the good themselves (Joewono 2009; Walton et al.; 2004). However, Russell (1996) has argued that being willing and able to pay for a commodity does not automatically imply being able to afford it, mainly because the social opportunity cost of the payment may be too high to be socially acceptable.

A methodological conclusion is that the use of pictorial choice cards in the presentation of choice scenarios offers great promise. Not only were all the expected advantages of the approach fully realized, but also the medium was believed to contribute in no little measure to obtaining the choice data and making the exercise more pleasurable to respondents (i.e., less of a burden). The survey instrument contributed to obtaining better responses and a higher response rate than if a different approach had been used. The survey approach is found to be most appropriate and effective to use in cases of hypothetical alternatives, particularly a novel SP survey approach in the context of a developing country with a high proportion of illiterate population.

**Acknowledgments**

The authors wish to thank the DART Agency and Dar-es-Salaam City Council for their logistical support and assistance throughout the field work. Insightful comments from Dr. Ir.Thijs Muizelaar are highly appreciated. The support by Ardhi University and input from colleagues Daan Menstrum and Niels Fikse is acknowledged. Further acknowledgment goes to Nuffic (NFP) for provision of funds to conduct the research. Finally, the authors appreciate the two anonymous reviewers for their helpful comments on the previous version of this paper.

**Endnotes**

1 Main daily activities in this study are defined as government/private office work, personal commercial business, and school.

2 It is important to note that more recent research concluded that D-efficient designs—the designs that minimize the D-error, that is, the elements included in the asymbiotical matrix of expected variance-covariance—produce significantly improved results in terms of statistical or relative efficiency (Rose and Bliemer 2009; Rose et al. 2008).
Unlabeled experiment is a choice experiment that uses generic titles for the alternatives where respondents make choices solely on the basis of the differences in attribute level values among the presented options (Louviere et al. 2000). This experiment does not attach a label to any of the alternatives.

References


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Just Who Should Pay for What? Vertical Equity, Transit Subsidy and Road Pricing: The Case of New York City

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Jonathan K. Kramer, Ph.D.
Kutztown University of Pennsylvania

Abstract

In this paper, equity and cross-subsidization issues associated with the congestion pricing scheme proposed as part of New York City’s PlaNYC are examined, as are initial usage patterns, user income distribution, and revenue distribution. We find that equity concerns surrounding the proposal are supported by economic analysis. If New York City is to revisit congestion pricing in the future and make it more politically palatable, it will need to find a way to mitigate these equity concerns.

Introduction

Governments at all levels across the United States are searching for new revenue sources to finance the maintenance, repair, and expansion of transportation infrastructure. Gasoline taxes have been the traditional source of funding for such work. However, as Puentes and Prince (2003) report, federal and state gas tax revenues have been decreasing when inflation is taken into consideration. With the public
generally unreceptive to increases in taxes, road pricing has become an integral part of many of the proposals to fund transportation infrastructure. One high-profile example of this is the congestion pricing scheme proposed by the mayor of New York City (NYC) in the spring of 2007. As one part of a sweeping master plan to make the city “greener” and more livable (PlaNYC 2007), Mayor Bloomberg proposed the creation of a cordon pricing system similar to the one implemented in London in 2003. While the mayor’s proposal had a “burgeoning coalition of civic and business organizations in support of congestion pricing” (Schaller 2010, p. 267), the legislation failed to garner enough support in the State Assembly to come to a vote. Lacking this authorization, the proposed congestion pricing system could not be implemented. The reasons for the failure of the plan to gain enough political support to successfully pass through the legislative process have been well documented by Schaller (2010) and Peters and Gordon (2009). One of the primary reasons cited for the failure of the plan to be implemented is related to social equity.

It is very difficult to accurately measure the equity implications of a proposed road pricing scheme because of the complexities of the transportation networks involved. This is especially true in New York City, where so many people are competing for a limited supply of routes into the Central Business District in Manhattan. It is also challenging to measure equity considerations because “... equity can be defined in many different and legitimate ways” (Ecola and Light 2009, p. 35). While other measures of equity are important—such as horizontal equity—in this paper, we focus on the vertical equity considerations of NYC’s proposed congestion pricing system. Vertical equity examines whether or not members of different income groups are treated differently. In a comprehensive review of why NYC’s congestion pricing scheme failed to gain enough support to be implemented, Schaller (2010) concludes that,

The short answer is that a relatively small group of users believed that congestion pricing was against their best interests. As with many large highway construction projects in the 1970s and 1980s, the extensive approval process required for congestion pricing offered auto users an avenue to block action. The intensive interests of one group were thus able to overcome widespread public support (p. 270).

These concerns led to successful political obstruction “... motivated by individual-level impacts on auto users” (Schaller 2010, p. 270). The auto users referred to were primarily from the outer boroughs, particularly eastern Queens and southern Brooklyn (see Figure 1).
A key component of the proposed pricing scheme was that it would generate additional revenue (roughly $420 million per year) (TCMC 2008) to fund improvements in transportation infrastructure. This revenue was to be managed by a special agency called “A Smart Authority” that would allocate the money to selected regional transportation projects, including roads and mass transit. The Metropolitan Transportation Authority (MTA), the major mass transit provider, proposed eight major mass transit capital projects valued at $951 million for initial funding from Smart Authority resources (TCMC 2008). Since funds would be generated from users of one mode of travel/corridor and used to subsidize users of another mode and/or another corridor, it is important to examine both the equity and cross-subsidization issues of the proposal. In this paper, we use data from a variety of sources to examine the validity of the vertical equity concerns surrounding NYC's proposed congestion pricing scheme.

**Literature Review**

The academic literature on equity and congestion pricing is voluminous and focuses much of its attention on how to measure equity and ways to remedy inequities so that proposals can be implemented. (For three surveys of this literature, see Levinson [2010], Ecola and Light [2009], and TRB Special Report 303 [2011].) One impediment to implementing congestion pricing, especially in the United States, is that new proposals are generally subject to the legislative process. It is interesting to note that the most high-profile implementation of congestion pricing is London, and that proposal was not subject to legislative approval process (Schaller 2010). As a result of having to pass the legislative hurdle, a great deal of attention has been given to how to make congestion pricing politically palatable.

Goodwin (1990) was among the first to emphasize the importance of using effective compensation schemes to overcome equity issues that fuel public/political resistance. The importance of effective compensation is now widely accepted in the literature. However, “Since so many factors determine the impacts of congestion pricing, revenue redistribution cannot solve all equity and fairness concerns” (Giuliano 1994, p. 275). Therefore, in addition to revenue redistribution, Oberholzer-Gee and Wech-Hannemann (2002) and Ison (1998) advocate focusing on the environmental goals of the program to motivate citizens to support the proposal.

Eliasson and Mattsson (2006) conclude that the two most important factors that determine equity impacts are how revenues will be used and initial travel patterns.
That is, the people currently making most of the trips will be the ones most affected by any change. Once again, comparing London to New York City, London had virtually no road tolls at the time of the implementation of its Congestion Pricing Scheme, whereas NYC has a mix of “free” and tolled bridges that “… has been imposed on a piecemeal basis without overall performance goals in mind” (Peters and Gordon 2009, p. 113). It is, therefore, important to study the characteristics of the current users of these facilities. This paper focuses specifically on users of the NYC facilities and their travel patterns and demographic characteristics to draw conclusions regarding the equity perceptions of the proposed congestion pricing scheme.

Ison (1998) recognized that the key issues surrounding any proposal “… must be addressed at the local level if the policy is to be saleable” (p. 21). As Schaller (2010) notes, although there was broad support for NYC’s congestion pricing proposal, Democratic Assembly members from the outer boroughs were deeply skeptical that “… the MTA would use the funds to make the promised service improvements” (p. 269). As a result, “With strong opposition from most of its NYC members, Assembly Democrats blocked a vote …” (Schaller 2010, p. 269) and the proposal died. To overcome such local resistance King, Manville, and Shoup (2007) recommend redistribution efforts that concentrate the benefits and create “strong advocates” for a proposal. They contend that congestion pricing schemes with concentrated benefits and widely-dispersed costs are more likely to succeed. In “Interim Report: An Inquiry into Congestion Pricing as Proposed in PlaNYC and S. 6068,” (Brodsky 2007), Assemblyman Brodsky concludes that “The Mayor’s congestion pricing proposal is a regressive tax whose burden is borne disproportionately by middle income New Yorkers, largely from the Bronx, Brooklyn, and Queens” (p. 10). This is consistent with Schaller’s (2010) observation that “… elected official support was strongest in Manhattan, the borough that is least auto-dependent…,” (p. 268) and that “the most vocal opposition came from elected officials and civic groups in the four NYC boroughs outside Manhattan” (p. 269). NYC’s congestion pricing scheme was perceived to have a broad range of benefits defused over a large population of commuters (including those from other states) with the middle class from the outer boroughs footing the bill.

Eliasson and Mattsson (2006) point out that there are many theoretical studies regarding the issues surrounding congestion pricing but few studies that make a quantitative assessment of the issues involved. This paper helps fill this gap in the literature by examining some of the equity concerns surrounding NYC’s proposed congestion pricing scheme using economic data collected by the Triborough Bridge and Tunnel Authority (TBTA), the NYC Independent Budget Office (IBO),
New Jersey Transit, and Rutgers University. In particular, we examine the impact of initial travel patterns, user income distribution, and revenue distribution on the political salability of the NYC congestion pricing proposal.

**Data Collection**

The TBTA—a.k.a. MTA Bridges & Tunnels—is the largest collector of tolls in the United States. In 2010, it collected $1.42 billion in tolls via 292 million transactions, with an average per vehicle fee of $4.86 (passenger vehicles and trucks combined) (URS 2011). Automobile users represent more than 90 percent of the total vehicles on its facilities (URS 2011).

In 2004, the TBTA conducted an origin-destination survey of its bridge and tunnel users. It typically conducts this type of survey every 8 to 10 years. In 2004, it distributed 304,000 surveys at cash toll lanes and mailed surveys to 329,000 E-ZPass (the local electronic toll collection [ETC] system) customers. (See Spitz et al. [2007] for a further description of the data.) Through a Freedom of Information Act request, the raw survey data from the TBTA was obtained, which contains 61,201 observations of passenger car usage on the 9 TBTA facilities in NYC.

Drivers from 44 states are represented in the data, but the vast majority of the tolls (97.2%) were collected from drivers from New York, New Jersey, and Connecticut. In addition, the data from the 2004 survey indicate that people living within 10 miles of a particular TBTA facility pay about one half of all of the tolls collected at that facility (Table 1). Almost two-thirds of all tolls are collected by users residing within 15 miles of the facility. This provides strong evidence that people who live near a facility are the primary users/toll payers of that facility. This is particularly important in the case of NYC, where regional equity concerns are an important issue.

The second set of data that we use in this study comes from the NYC IBO. In 2003, the IBO reported the results of its analysis of the 1998 New York Metropolitan Transportation Council’s Regional Travel–Household Interview Survey conducted by the regional metropolitan planning organizations (MPOs) on transit users and automobile users of the un-tolled Harlem and East River bridges (IBO Fiscal Brief 2003). The IBO study was conducted to determine how much revenue would be collected and who would pay, both in terms of place of residence and household income, if the City started tolling these “free” bridges. The study did not examine congestion pricing alternatives nor did it look at the effect of tolls on traffic. However, the tolling of these “free” bridges became an integral part of NYC’s congestion...
pricing proposal in 2007 (in that the potential to toll these facilities was considered as an alternative to developing a pricing zone). Examining the data provided by this study alongside the data from TBTA’s origin-destination survey allowed us to develop a baseline profile of tolling in NYC prior to the proposed implementation of congestion pricing. This shed new light on why perceptions of regional inequity were so strong.

Table 1. Percent of Tolls Collected from Users Who Live Within 5, 10, and 15 Miles of a TBTA Facility

<table>
<thead>
<tr>
<th>Facility</th>
<th>5 miles (%)</th>
<th>10 miles (%)</th>
<th>15 miles (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Verrazano-Narrows Bridge</td>
<td>27.8</td>
<td>52.4</td>
<td>62.8</td>
</tr>
<tr>
<td>Throgs Neck Bridge</td>
<td>13.5</td>
<td>38.9</td>
<td>54.9</td>
</tr>
<tr>
<td>Triborough Manhattan Bridge</td>
<td>35.4</td>
<td>57.4</td>
<td>72.4</td>
</tr>
<tr>
<td>Triborough Bronx Bridge</td>
<td>24.1</td>
<td>54.3</td>
<td>69.7</td>
</tr>
<tr>
<td>Queens Midtown Tunnel</td>
<td>23.1</td>
<td>40.8</td>
<td>54.5</td>
</tr>
<tr>
<td>Marine Parkway Bridge</td>
<td>65.3</td>
<td>85.2</td>
<td>93.9</td>
</tr>
<tr>
<td>Henry Hudson Bridge</td>
<td>19.9</td>
<td>50.2</td>
<td>67</td>
</tr>
<tr>
<td>Cross Bay Bridge</td>
<td>19.4</td>
<td>60.3</td>
<td>82.5</td>
</tr>
<tr>
<td>Brooklyn Battery Tunnel</td>
<td>21.8</td>
<td>71.2</td>
<td>87.3</td>
</tr>
<tr>
<td>Bronx Whitestone Bridge</td>
<td>18.7</td>
<td>44.7</td>
<td>60.6</td>
</tr>
<tr>
<td>All Facilities</td>
<td>24.0</td>
<td>50.4</td>
<td>64.4</td>
</tr>
</tbody>
</table>

*See Figure 1 for facility locations*

Data on other classes of commuters into the central business district also was examined, in particular, data on New Jersey-based commuter rail travelers (New Jersey Transit’s 2005 Rail User Origin-Destination Survey) and New Jersey-based toll bridge, tunnel, and highway users (Yanmaz-Tuzel et al. 2010). In both cases, it was found that the New Jersey-based commuter rail users and toll facility users exhibited characteristics very similar to those of users on the New York side of the metro region.

**Bridges, Tunnels, and PlaNYC**

The proposed congestion pricing zone for NYC was very similar in design to the London Congestion Charging Scheme launched in 2003. Similar to London, one of the cornerstones of NYC’s congestion pricing proposal was a daily fee ($8 in the case of NYC) for autos traveling into Manhattan (south of 86th Street) on weekdays between 6 a.m. and 6 p.m. However, unlike London, drivers would be given credits for tolls paid on bridges and tunnels in the city. Thus, according to the proposal,
at the then-existing toll rates, no driver would have paid more than $8 per day in fees to drive in the zone. From Figure 1, it is easy to speculate why this proposal caused serious regional equity concerns. As Schaller (2010) points out, “... New Jersey commuters would pay little or nothing in congestion fees (due to the toll offsets), while commuters from Queens, Brooklyn, and the Bronx who use the free bridges would pay the full $8 fee” (p. 269). Schaller (2010) also points out that regional equity concerns were “... amplified by outerborough residents’ and elected officials’ traditional resentment of Manhattan-based elites“ (p. 269). Manhattan residents are the least reliant on automobile transportation and most likely to benefit from expanded public transportation. They would also benefit the most from the reduction of environmental externalities caused by automobile commuting into the central business district.

Figure 1. Proposed congestion pricing zone for New York City with free and toll facilities
Initial Usage Patterns

As mentioned previously, Eliasson and Mattsson (2006) point to initial travel patterns as being very important for determining equity impacts because the people making most of the trips will be the ones most affected by any change. King et al. (2007) provide a succinct framework in which to measure congestion pricing’s winners and losers based on initial travel patterns:

Even before considering the use of the revenue, congestion pricing will create a net benefit for two groups because of improved traffic flow:

1. Drivers whose time saved is worth more than the tolls they pay.
2. People who already use transit and will not pay tolls but will travel faster.

Again, before considering the use of the revenue, congestion pricing will create a net loss for three other groups:

3. Drivers whose time saved is worth less than the tolls they pay.
4. Drivers who switch to a less convenient route to avoid the tolls.
5. People on non-tolled routes whose traffic increases when drives from Group 4 switch to their roads. (p. 113)

While this framework ignores the impact of revenue distribution, we consider that in the next section.

In the case of NYC’s congestion pricing proposal, enough people perceived themselves to be in categories 3–5 above to impede implementation. At the time of deliberation on the proposal, there was not a great deal of publicly-available quantitative analysis of “net gainers” and “net losers.” One exception was found in Brodsky (2007), who cited statistics based on the average citizen (not user) from Manhattan and the outer boroughs. He reports that the average person paying the congestion fee would pay approximately $2,000 per year in order to commute at an increased speed of 0.6 miles per hour within the zone (Brodsky 2007). This represents 4.2 percent of the annual income of a resident of the Bronx, Brooklyn, and Queens (Brodsky 2007), but only 2.5 percent of the annual income of a resident of Westchester or Manhattan. Thus, he found the congestion pricing scheme to be regressive in nature. Further, he states that even if lower-income people benefit disproportionately from improvements in mass transit funded by new revenue, “the revenues are largely raised from people of moderate income” (Brodsky 2007, p. 12). Many of these people would be “free” bridge users who the IBO (2003) also identifies as “… moderate-and middle-income suburbanites who are more likely to drive than take transit” (p. 1).
Just Who Should Pay for What? Vertical Equity, Transit Subsidy and Road Pricing

Extending Brodsky’s (2007) analysis, we are able to deduce the following regarding potential impacts on the average person. First, users of facilities that currently charge tolls would receive a daily credit towards the congestion fee equal to the tolls paid each day. In some cases (e.g., the Verrazano-Narrows Bridge serving Staten Island), these credits would completely offset the congestion fee. These individuals (those who currently use facilities with a net increase of zero in Table 2) would likely consider themselves in Category 1 of King et al.’s (2007) classification and, thus, net beneficiaries of the congestion pricing scheme.

Second, some users would receive only a partial or no offset of the congestion fee from tolls. Whether or not these individuals would realize a net benefit or net loss depends on the speed and length of their trip within the zone and the value of their time. To further understand the speed conditions in the proposed pricing zone, the new GPS tracking data from the NYC Taxi and Limousine Commission were used to estimate existing travel speeds and distances within the proposed zone.

### Table 2. Hourly Cost of Time Savings Based on Initial Usage Patterns

<table>
<thead>
<tr>
<th>Facility</th>
<th>Congestion Fee</th>
<th>Round Trip Toll Credit (Cash toll)</th>
<th>Net Increase</th>
<th>Hourly Cost</th>
<th>Equivalent Annual Salary (After-Tax)</th>
<th>No. of Bridges</th>
</tr>
</thead>
<tbody>
<tr>
<td>Harlem River</td>
<td>$8.00</td>
<td>$0.00</td>
<td>$8.00</td>
<td>$113.48</td>
<td>$236,046</td>
<td>9</td>
</tr>
<tr>
<td>East River</td>
<td>$8.00</td>
<td>$0.00</td>
<td>$8.00</td>
<td>$113.48</td>
<td>$236,046</td>
<td>4</td>
</tr>
<tr>
<td>Cross Bay</td>
<td>$8.00</td>
<td>$4.50</td>
<td>$3.50</td>
<td>$49.65</td>
<td>$103,270</td>
<td>1</td>
</tr>
<tr>
<td>Marine Parkway</td>
<td>$8.00</td>
<td>$4.50</td>
<td>$3.50</td>
<td>$49.65</td>
<td>$103,270</td>
<td>1</td>
</tr>
<tr>
<td>Henry Hudson</td>
<td>$8.00</td>
<td>$4.50</td>
<td>$3.50</td>
<td>$49.65</td>
<td>$103,270</td>
<td>1</td>
</tr>
<tr>
<td>Verrazano-Narrows</td>
<td>$8.00</td>
<td>$9.00</td>
<td>$0</td>
<td>$0</td>
<td>$0</td>
<td>1</td>
</tr>
<tr>
<td>Triborough Bronx</td>
<td>$8.00</td>
<td>$9.00</td>
<td>$0</td>
<td>$0</td>
<td>$0</td>
<td>1</td>
</tr>
<tr>
<td>Triborough Manhattan</td>
<td>$8.00</td>
<td>$9.00</td>
<td>$0</td>
<td>$0</td>
<td>$0</td>
<td>1</td>
</tr>
<tr>
<td>Bronx Whitestone</td>
<td>$8.00</td>
<td>$9.00</td>
<td>$0</td>
<td>$0</td>
<td>$0</td>
<td>1</td>
</tr>
<tr>
<td>Throgs Neck</td>
<td>$8.00</td>
<td>$9.00</td>
<td>$0</td>
<td>$0</td>
<td>$0</td>
<td>1</td>
</tr>
<tr>
<td>Brooklyn Battery Tunnel</td>
<td>$8.00</td>
<td>$9.00</td>
<td>$0</td>
<td>$0</td>
<td>$0</td>
<td>1</td>
</tr>
<tr>
<td>Queens Midtown Tunnel</td>
<td>$8.00</td>
<td>$9.00</td>
<td>$0</td>
<td>$0</td>
<td>$0</td>
<td>1</td>
</tr>
</tbody>
</table>
Based on a sample of 500,000 taxi trips in NYC in February 2010, we find that 101,187 of these trips both originated and terminated within the proposed zone during peak hours and that the average speed for taxis within the zone was 11.00305 mph. As an outer bound on distance, we assume that a person drives from one end of the zone to the other and back each day (15 miles). While this is unlikely to be the case, if individuals with such a lengthy commute (thus benefiting greatly from reduced congestion) consider themselves to be in Category 3 of King et al.’s (2007) classification, then almost all of those following the same route into the zone will as well. Table 2 shows that users receiving a partial offset from tolls would be paying $49.65 in after-tax dollars per hour of time savings. Those receiving no offset would be paying $113.48 in after-tax dollars per hour of time savings. According to Brodsky (2007), the average before-tax income of someone from the Bronx, Brooklyn, and Queens is $23/hour. Thus, even with a very long commute within the zone and ignoring taxes, the average person commuting from the outer boroughs across the “free” bridges into Manhattan would consider themselves to be in Category 3.

The hourly savings of $49.65 and $113.48 roughly equate to annual after-tax salaries of $103,270 and $236,046, respectively. According to the IBO (2003) survey results, only 26 percent of NYC resident auto drivers who reported their income on the survey of “free” bridge users earn a before-tax income in excess of $100,000 per year. That means that even with a long commute in the zone (15 miles) and ignoring taxes, at least three-quarters of the NYC drivers using the “free” bridges would view themselves, before considering the benefits of distribution of the revenue, as net losers from the congestion pricing proposal. 2

Since the outer boroughs are relatively underserved by mass transit relative to Manhattan (Figure 2), many current bridge users would also perceive themselves as falling into Category 4 (drivers who switch to a less convenient route to avoid the tolls). From these statistics, it is easy to understand why middle-class people from the outer boroughs currently served by “free” bridges were unlikely to be advocates of the NYC congestion pricing proposal. Most would perceive themselves in categories 3–5 (net losers) of King et al.’s (2007) framework.

King et al. (2007) point out that the economic stumbling blocks cited above are compounded by the psychological considerations of loss aversion and the free rider problem. Loss aversion is “… the reluctance to part with a benefit one already has, and the tendency to view a new benefit—even one of equal or greater value—as less desirable than the one given up.” (King et al. 2007, p. 114). This would most cer-
tainly be applicable to all of the users of NYC’s “free” bridges, regardless of whether or not their time saved is worth more or less than the new fee paid; they were being asked to give up something they were getting for free for an unspecified benefit.

The free rider problem refers to the fact that “even if most drivers think they would be better off with congestion tolls, no one will be so much better off that they will take the lead to implement the program” (King et al. 2007, p. 114). So, despite the fact that there were some net beneficiaries in the outer boroughs, at the individual level they did not perceive themselves to be so much better off that they banded together to become advocates for the proposal. On the contrary, a relatively small group experiencing concentrated costs organized to defeat the proposal. Schaller (2010) points out that in the areas of greatest resistance—Queens and southern Brooklyn—only 5 percent of workers commute by car into the Manhattan central

Figure 2. Outer borough access to subway system (½-mile walk)
business district. This ability of a small group to wield great influence is not entirely surprising since King et al. (2007) point out that small groups are actually easier to organize and, if organized properly, can outmaneuver large but poorly-organized groups of opponents. Therefore, in order to create strong advocates who will persuade people of the need for congestion pricing, King et al. (2007) recommend concentrating benefits. However, as Schaller (2010) reports, opponents were skeptical that “… the MTA would use the funds to make the promised service improvements” (p. 270). This skepticism, combined with the short amount of time available for public discussion and dissemination of the revenue distribution plan (October 2007–April 2008 [Gordon and Flanagan 2012]), made the free rider problem difficult to overcome.

Facility Users vs. the Background Population

In this study, Lorenz curves and Gini coefficients were used to assess the vertical equity and cross-subsidization concerns relating to income. Lorenz curves provide a graphical representation of the extent of inequality between the actual distributions of resources and perfect proportionality. Figure 3 shows the income profiles of the background populations within 15 miles of each TBTA facility. The straight line that extends from the origin represents proportional equity. Each Lorenz curve depicts the degree of income inequality of the background populations surrounding each facility (within 15 miles of each facility). The further to the right that a Lorenz curve bows, the less equitable is the income distribution. Since NYC is a relatively concentrated area—27,012 people per square mile, 309 times the national average (U.S. Census 2010)—there is little difference in the demographic makeup of the background populations when measured in this way.

Figure 4 shows that the Lorenz curves for the users of the nine tolled TBTA facilities relative to the background population of each facility. Measured this way, significant differences between users and residents are observable. Gordon and Peters (2011) conclude that this occurs because income becomes a more important determinant of who uses a facility when untolled alternatives are available (e.g., Queens Midtown Tunnel), and that when there are no, or poor, alternatives (e.g., Verrazano-Narrows bridge), proximity to the facility becomes a more important determinant of usage. While general observations can be made by looking at Lorenz curves, Gini coefficients facilitate comparisons.
Figure 3. Income profiles of background populations

Figure 4. Income profiles of users of tolled TBTA bridges
Gini coefficients are calculated by determining the area below the equity line and above the corresponding Lorenz curve. Using the sources listed above, Gini coefficients were calculated based upon the reported income distributions for the “free” bridges, as well as New York transit users and New York and New Jersey commuter rail users. The resulting coefficients (and median incomes) are presented in Table 3. A Gini coefficient of 0 represents complete equity, whereas a coefficient of 1 represents complete inequity. Since the background characteristics of users are so similar (Figure 3), we are able to compare across facilities based on their individual Gini coefficients.

The Gini coefficients in Table 3 range from 0.2665 for NYC residents using public transportation to cross the Harlem River to 0.7952 for users of the Queens Midtown Tunnel. The Gini coefficients for the U.S. and New York State are 0.4689 and 0.4985, respectively. Based on this analysis, we can further explore the relative impact of various pricing and subsidy proposals on different income groups. For example, NYC resident users of the “free” bridges are generally of more moderate income than users of the tolled facilities. These are the users who would be most significantly impacted by the proposed congestion pricing scheme since they currently pay zero but would have to pay the full congestion fee without any toll offset. They are neither the highest nor lowest income cohort, but, as suggested by other studies, they are in the middle of the income distribution. They would either have to pay a fee that, as the previous example in this paper illustrates, is greater than their time saved or switch to a less convenient mode (mass transit) to avoid the fees. In both instances, they would be more likely to perceive themselves to be “net losers” as characterized by King et al.’s (2007) classification scheme and unlikely to support the congestion pricing proposal.

Revenue Distribution
Numerous studies have pointed to the importance of the allocation of the toll revenue to making congestion pricing politically palatable. Santos and Rojey (2004) show that road pricing can be progressive, regressive, or neutral depending on where people live, where they work, and how they get to work. They also find “…that towns that suffer regressive impacts from a congestion charging scheme, could reverse the situation with an appropriate use of revenues” (Santos and Rojey 2004, p.38). The Gini coefficients in Table 3 support Brodsky’s (2007) contention that the congestion charge revenue would be raised largely from people of moderate income. It is less clear that allocating revenues to public transportation will make
Table 3. Gini Coefficients for All Bridges and Public Transit

<table>
<thead>
<tr>
<th>Public Transit Users</th>
<th>GINI Coeff.</th>
<th>GINI Rank</th>
<th>Median Income</th>
<th>Income Rank</th>
<th>Agency</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>NYC Resident Users</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Harlem River</td>
<td>0.2665</td>
<td>1</td>
<td>$34,615</td>
<td>1</td>
<td>NYC Transit</td>
</tr>
<tr>
<td>East River</td>
<td>0.4033</td>
<td>2</td>
<td>$48,370</td>
<td>2</td>
<td>NYC Transit</td>
</tr>
<tr>
<td><strong>Non-NYC Resident Users</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Harlem River</td>
<td>0.6940</td>
<td>15</td>
<td>$98,750</td>
<td>16</td>
<td>Metro North</td>
</tr>
<tr>
<td>East River</td>
<td>0.6939</td>
<td>14</td>
<td>$100,001</td>
<td>17</td>
<td>LIRR</td>
</tr>
<tr>
<td>NJ Transit North Rail (Hudson River)</td>
<td>0.6951</td>
<td>16</td>
<td>$101,795</td>
<td>18</td>
<td>NJ Transit</td>
</tr>
<tr>
<td><strong>“Free” Bridge/Tunnel Users</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Harlem River</td>
<td>0.5471</td>
<td>5</td>
<td>$63,000</td>
<td>4</td>
<td>NYC DOT</td>
</tr>
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the results less regressive. Net proceeds from road pricing activities are often allocated in some part to mass transit (NYC agencies currently allocate over 50 percent of existing road toll revenue to mass transit) for the purposes of improving the environment, reducing congestion, and making the proposal less regressive. While the first two of these arguments may be valid for the NYC congestion pricing proposal, the third does not seem to hold in all cases. Columns 3 and 5 of Table 3 rank the various systems that one can use to reach Manhattan based on their potential strength to reduce the regressivity of the proposal. The lower the number ranking, the greater the potential a particular route has to reduce the regressive nature of the proposal. As the rankings indicate, funding mass transit across the Harlem and East River bridge corridors for NYC residents would contribute significantly to the goal of making the scheme less regressive for NYC residents. However, this could be offset largely by the benefits to high-income, non-NYC residents who are entering the city via mass transit. As the IBO (2003) report points out: “City residents who drive across the free bridges have higher average incomes than city residents who enter Manhattan via subways and buses. In contrast, suburban residents who enter Manhattan by mass transit are generally more affluent than suburban drivers” (p. 1).

The data support the contention that revenue would be raised largely from NYC residents of moderate income. Without a detailed plan and commitment for revenue allocation, it is unclear whether the plan would ultimately be progressive, regressive, or neutral. Therefore, any revenue redistribution scheme would have to take into account the income disparities outlined in Table 3 if it hoped to build the kind of political support necessary for implementation.

Conclusion

The vertical equity impacts of congestion pricing schemes are largely dependent upon initial usage patterns, how the revenue raised is allocated, and environmental impacts. Congestion pricing schemes with concentrated benefits and widely-dispersed costs are more likely to be implemented. The NYC congestion pricing proposal included in PlaNYC was perceived to concentrate the costs and disperse the benefits, which contributed to its failure to garner enough political support to be implemented. We show that these perceptions are supported by economic analysis of data from various sources. If NYC is to revisit congestion pricing in the future, it will need to find a way to spread out the costs and/or concentrate the benefits to those bearing significant burdens.
This paper also explores the complex question of cross-subsidization of mass transit services. Pricing automobile travel and using the revenue to fund mass transit services can both encourage a reduction in automobile use and create a more equitable source of funding for mass transit. However, as the results of this study indicate, it is important to consider what route is priced as well as what transit system is going to be subsidized to evaluate the potential equity outcomes from a road pricing and transit subsidy program. In this case, subsidization from the East River and Harlem River bridge users to New York or New Jersey commuter rail systems would result in a net reduction in the social equity.

With careful analysis, the potential exists to develop a pricing scheme that targets the burden of the tolls more heavily on facilities that have a preponderance of users who have high incomes. The fact that you can fine-tune prices to generate given amounts of revenue from a target base of users is one of the great advantages of road pricing. For example, by targeting facilities with higher-income users such as the Henry Hudson Bridge and using that revenue to subsidize transit services that serve mostly moderate-income users, such as MTA’s Subway service, the potential exists to cross-subsidize in a progressive way using road fees.

Existing and proposed taxation systems have varying ranges of progressivity or regressivity in terms of vertical equity. As such, a detailed analysis of any proposed pricing and subsidy program should be considered, and the environmental, traffic, and social equity measures can be examined and balanced to produce a more just, sustainable, and efficient system of pricing and operations.

Endnotes

1 London had an extensive system of toll gates on major turnpikes in the 18th and 19th centuries. These were almost completely eliminated in favor of other revenue mechanisms in the late 19th century. One notable exception is the toll gate on the Dulwich Estate, which was established in 1789 and still operating today (however, its function today is more to control traffic flow and is historic in nature, as opposed to a major revenue source). In addition, London City bridges are built and maintained by The City Bridge Trust, a public trust that dates to the 12th century. The Trust maintains these facilities without currently charging tolls, thanks to an endowment that was generated from tolls, real estate investments, and other funds.
It is likely that time savings would be realized outside of the zone as well. The Report to the Traffic Congestion Mitigation Commission & Recommended Implementation Plan (2008) includes estimates of VMT reduction by sub-region. However, the estimated reductions in VMT outside of the zone are considerably smaller than inside the zone (6.7% reduction for Manhattan South of 86th St. vs. 1.9%, 2%, 1.5%, and 1.3% for the Bronx, Brooklyn, Queens, and Staten Island, respectively); it is not clear how much of this reduction in VMT would accrue to those actually paying the congestion fee.

We show the existing metro rail network as our primary measure of transit services. Commuting to the Zone from the outer boroughs represents a very long commute, and local bus service is less likely to be a good substitute for auto travel.

References


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The Perils of Participation: The Effect of Participation Messages on Citizens’ Policy Support

Geneviève Risner and Daniel Bergan
Michigan State University

Abstract

While scholars have found several benefits to citizens, government, and society resulting from participatory policy processes, other research suggests that citizens are apathetic and uninterested in participating in policy-making. Also, in some cases, knowing that similar others participated in making a decision can decrease support for the result. The current research attempts to determine whether knowledge that similar citizens participated in public transportation policymaking or elites designed a transit policy affects support for the policy as well as general support for the policy process. Results from a survey experiment suggest that who participates matters. Citizens do not want “people like them” developing public transportation policies. These findings pose implications for the promotion of participatory processes.

Introduction

Transit agencies face increasing requirements to engage the public in strategic planning. In 2007, the Federal Transit Administration (FTA) proposed a new circular on Environmental Justice (FTA C 4702.1A) that provided guidance on promoting inclusive public participation. The circular stated, “An agency’s public participation strategy shall offer early and continuous opportunities for the public to be involved in the identification of social, economic, and environmental impacts of
proposed transportation decisions” (U.S. Department of Transportation 2007: 21). Additionally, 23 CFR 450.210 mandated that recipients of federal transportation funds have public participation plans that engage the public in long-range, strategic transportation planning (Michigan Department of Transportation 2010). Without such public participation, transit agencies are ineligible for federal funding. As transit professionals seek to implement participatory processes, understanding the effect of the messages used to educate the public that these engagement efforts occurred becomes important for later public support of resulting transit policies.

Aside from receiving federal funding, involving citizens in transportation planning may have several positive effects. First, citizen engagement upholds democratic ideals that “[e]very citizen should have an equal chance to influence government policy” by allowing people an opportunity to voice their opinions (Prothro and Grigg 1960: 282). Second, public participation can improve policy-making (Fishkin 1995). Specifically, discussion can improve decision-making by combining participants’ information and enlarging the range of arguments for or against a given policy (Rawls 1971). Third, citizen participation in democratic processes may lead to a more informed citizenry, individual empowerment, constructive communication, and actualization of desired outcomes (Irvin and Stansbury 2004).

Furthermore, the benefits of increased citizen involvement in decision-making may extend beyond the participants and policymakers to the broader society. In particular, “[i]f citizens realize that a particular policy was based on deliberation, they will consider the policy to be more legitimate” (Irvin and Stansbury 2004; Ely 1980: 181). Additionally, civic engagement can increase trust in government (Keele 2007; Putnam 1995) or institutions (Beierle 1999).

Just having the perception that participation occurred, as opposed to being an actual participant, can create positive outcomes. For example, Tyler et al. (1985) found, in an experiment where subjects responded to written scenarios about a city council, that respondents reacted more favorably when the council solicited public input. Thus, merely knowing that other citizens participated directly in designing a policy may result in more satisfaction with policy outcomes and trust in government (Kweit and Kweit 2007).

Although participation in democratic processes may have several positive outcomes, other research suggests that engaging the masses in politics may not be an effective strategy because people simply do not wish to be involved. Some scholars suggest that many people do not and prefer not to think about politics on a daily basis (Hibbing and Theiss-Morse 2002).
The last thing people want is to be more involved in political decision-making: They do not want to make political decisions themselves; they do not want to provide much input to those who are assigned to make these decisions; and they would rather not know all the details of the decision-making process. (Hibbing and Theiss-Morse 2002: 1)

Many citizens prefer to rely on the guidance of others to make policy-related decisions rather than become engaged in politics themselves. These attitudes suggest that citizens prefer representative government and, more particularly, a “trustee” model of representation, rather than a deliberative form of policy-making. In the trustee model of representation, “[t]he representatives act not as agents of the people but simply instead of them. We send them to take care of public affairs like hired experts, and they are professionals, entrenched in office and in party structures.” (Pitkin 2004; 339). Many citizen’s believe that “[t]he ideal form of government, …, is one in which they can defer virtually all political decisions to government officials but at the same time trust those officials....” (Hibbing and Theiss-Morse 2002: 159).

Aside from some individuals’ aversion to participation in decision-making, there are other reasons to think that deliberation may actually decrease the legitimacy of policies. Some literature suggests that policies made by other people “just like me” may have a negative consequence on support for a position. When the average citizen does not possess knowledge on a particular topic, he may assume that other people “just like him” also have little knowledge on that topic (Goethals and Nelson 1973). In this case, the fact that similar others participated in developing a policy could have adverse consequences for policy support.

Thus, the literature appears somewhat divided on the issue of participation. One line of scholarship from the area of participatory governance advocates citizen participation in policy-making. When citizens are engaged in policy-making, democratic ideals are upheld and trust is instilled in actual participants as well as those who perceive that other citizens were given an opportunity to voice their opinions. Conversely, another line of scholarship indicates that citizen participation may have adverse consequences. Not only are many citizens apathetic, but they prefer to have elected representatives engage in policy-related discussions and decisions. Furthermore, knowing that a participatory process occurred among similar others could actually decrease support for a policy, especially if the topic addresses an issue on which most people are not knowledgeable (Goethals and Nelson 1973).
Therefore, this paper raises the following question: How does support for a policy change by knowing similar citizens participated in public transit policy-making or that elites designed a transit policy? This research attempts to answer this question with a survey experiment that followed a community-based participatory process that engaged citizens and elites in a countywide public transportation planning process.

**Participation by Proxy**

While scholars have focused on the effects of direct participation on citizen support for policies and other attitudes, other scholars have studied the effects of citizen participation in policy-making on other citizens’ attitudes and diffuse support for democratic institutions. Tyler (1990) found that people place importance on perceptions of procedural justice or fairness. When people believed they had an opportunity to share their opinions, even if stating their case did not result in the desired outcome, they felt the process was legitimate and reported positive opinions of actors in the criminal justice system such as judges and police officers (Tyler 1990).

Kweit and Kweit (2007) examined whether these findings applied in a broader community context. They studied the effects of actual participation (engagement in ongoing planning meetings) and perceptions of participation (one’s sense that government had made effort to engage community members in planning meetings) on satisfaction with and trust in local government through a phone survey of 600 residents in 2 neighboring communities 5 years after a flood. They found that actual participation caused statistically insignificant decreases in trust in and satisfaction with local government. However, perceptions of participation by others resulted in significant positive relationships with trust and satisfaction with local government. Kweit and Kweit (2007) concluded, “... the symbolic role of participation may be more important than its instrumental role” (407).

Although Kweit and Kweit’s (2007) research provides some evidence that perceptions of participation can be important, they do not provide evidence regarding whose input is valued. In the communities that Kweit and Kweit studied, all citizens had an open invitation to participate, but “key leaders were targeted to receive invitations” for community input sessions (Kweit and Kweit 2007: 419). Additionally, one community created a task force of 15 “prominent leaders” per the request of the business community (Kweit and Kweit 2007). As a result, their findings sug-
suggest that the perception that community leaders participated in policy development may be more important than knowing similar others (i.e., ordinary citizens) participated.

**Similarity**

Similarity may be one causal mechanism for explaining why perception of participation by other citizens may increase as well as decrease citizen support for a policy. In many cases, similarity has resulted in persuasive outcomes, causing attitude formation or change to align with that of the communicator (Cialdini 2001). Similarity is an effective persuasive tool because “we like people who are similar to us” (Bryne 1971). The effect of similarity on liking has been found for commonalities in age, religion, smoking habits (Evans 1963), names (Garner 2005), political party (Furnham 1996), and attire (Emswiller et al. 1971; Suedfeld et al. 1971). In particular, when the issue in question refers to a value (i.e., evaluation of the goodness or badness of an object, entity, or state of affairs), people are more likely to be influenced by their peer or membership group (Goethals and Nelson 1973; Jones and Gerard 1967).

However, dissimilarity can be persuasive when an issue emphasizes a belief (i.e., can be proven correct or incorrect) (Goethals and Nelson 1973; Jones and Gerard 1967). While this is the first study, to the authors’ knowledge, to assess the effect of dissimilarity (similarity) on policy attitudes, several studies support the persuasive power of dissimilar “experts” in contexts dealing with beliefs (Suls et al. 2000; Goethals and Nelson 1973; French & Raven 1959). In situations where dissimilarity is seen as providing a strategic advantage, people may form or change an attitude to align with the dissimilar other. Knowledge is one form of dissimilarity shown to result in such effects. Thus, in the case of some complex policies, such as public transportation, knowledge possessed by community elites may create a strategic advantage. When this is the case, the general public should find dissimilarity to be persuasive and rely on the expertise of knowledgeable others to form their opinions.

In policy-making situations where the public “has little knowledge or information,” many organizations have used participatory processes (Fishkin n.d.). Some of these local U.S. policy-making situations involve issues such as taxes and spending, energy use, and conservation (Fishkin n.d.). We argue that several other types of policy issues are “often technically complex and value-laden” (see Bierle [1999] for a discussion of environmental policies being technically complex and value-laden,
Therefore, like most policy issues, local public transportation relates to both beliefs and values.

**Hypotheses**

Underlying the foundation of American government is the idea that people should have a voice in the policy-making process. Even when the outcome is counter to what one hoped, when people feel they have been given the opportunity to state their case—creating a fair process—they have more positive feelings toward political actors and a greater sense of legitimacy of the process (Tyler 1990). When people believe elected officials have attempted to engage ordinary citizens in the policy-making process, this fosters a sense of legitimacy (Hibbing and Theiss-Morse 2001). Thus, if community residents are told that other community members “just like them” participated in developing a local policy, we would expect that support for the policy will be greater after people hear a message emphasizing that people like them participated in a policy-making process (H1a).

However, when people believe that the policy topic is one that they—and people like them—are not knowledgeable about, knowing that a participatory process occurred among similar others could actually decrease support for a policy (Goethals and Nelson 1973). In this case, we would expect that support for the policy will decrease after people hear a message emphasizing that people like them participated in a policy-making process (H1b). These competing frameworks suggest the following research question: How does knowing that similar others participated in a policy-making process affect support for the policy?

In addition, most people do not and prefer not to think about most political issues (Hibbing and Theiss-Morse 2002). Rather, people rely on elected representatives to make policy-related decisions (Pitkin 2004). Additionally, if an issue is related to a belief, dissimilarity will affect a citizen’s policy position (Goethals and Nelson 1973). Plus, given Kweit and Kweit’s (2007) findings, it is possible the perception of participation by community leaders in policy development is more important than knowing similar others participated. Therefore, for issues that people believe community leaders are better equipped to solve than the average citizen, we would expect support for the policy will be greater after people hear a message emphasizing that community leaders participated in a policy-making process (H2a).

However, citizens have a desire for procedural justice (Tyler 1990); they want to be given the opportunity to voice their opinions (Hibbing and Theiss-Morse 2001).
When processes are limited to community leader involvement and citizens are excluded from a decision-making process in which they wanted to be involved, we would expect support for the policy would decrease after people hear a message emphasizing that community leaders participated in a policy-making process (H2b). These competing frameworks suggest a second research question: How does knowing that community leaders participated in a policy-making process affect support for the policy?

**Method**

The independent variable in this study was participation message type (community members vs. community leaders) with an off-set control group that was not informed about who was involved in designing the public policy. The dependent variables were verbal support for the policy and behavioral support for the policy.

**Sample**

A total of 600 registered voters throughout one Midwestern county served as participants in the current study (female, 66%). Of participants, 19.7 percent reported an annual household income of less than $25,000 per year, 26.8 percent reported earning $25,001–$50,000 per year, 17.5 percent reported earning $50,001–$75,000 per year, 15.8 percent reported earning more than $75,000 per year, and 20.2 percent refused to provide a response or did not know their annual household income. Participants ranged in age from 18–65+. Specifically, 35.8 percent of respondents reported ages of 50–65, 34.8 percent were 65+, 22.2 percent were 31–49, 3 percent were 18–24, 2.7 percent were 25–30, and 1.5 percent refused to provide their age.

**Procedure**

The survey followed a year-long community-based public transportation planning process. The goal of the planning process was to design a five-year strategic transit plan for Allegan County Transportation (ACT), a rural transportation system that provides approximately 47,000 demand-response rides per year (Allegan County Transportation 2010).

The engagement process employed several phases. Phase 1 included a stakeholder survey and focus groups in which community organizations (e.g., churches, hospitals, employers, nonprofit organizations) were identified and asked to complete an online survey to identify how they are meeting the transportation needs of their clients and recommend improvements to the current ACT system. Following survey completion, six focus groups with a sample of the participants were conducted.
to further discuss their client’s transportation needs and make recommendations to improve ACT services (Disability Network/Lakeshore 2012).

Phase 2 consisted of a current rider survey, which sought input on unmet transportation needs of existing ACT riders and provided opportunities for input on ACT improvements; a prospective transit survey, in which community organizations tracked unmet transportation needs of people seeking rides that could not be provided given limited resources; and one-on-one interviews with previous ACT riders with unmet transportation needs, again allowing opportunities for input on recommended changes. Based on analysis of data collected through these two phases, a workgroup of community partners created five transportation options for improvements to ACT (Disability Network/Lakeshore 2012).

Phase 3 included 10 community input sessions that sought feedback from the general public on the 5 options. Community organizations promoted the event through flyers, and a listing of input sessions was posted in two local newspapers. The results of the input sessions were analyzed and used to create a draft five-year strategic plan for ACT (Disability Network/Lakeshore 2012). The three phases engaged approximately 1,000 local residents and 200 community leaders in focus groups, surveys, and input sessions.

The current experiment was embedded in Phase 4, a phone survey of taxpayers throughout Allegan County, which includes 11 cities and 24 townships. The taxpayer survey was designed to assess a variety of public opinions on local public transportation providers and issues, support for features of the five-year strategic plan, and identify potential, effective messages to use to promote the final plan.

An independent survey firm was hired to conduct phone surveys with registered voters. Phone surveys were conducted during December 2009. Within the context of this survey, participants were asked whether they or someone they know had an unmet transportation need in the past 12 months. After a series of questions related to their attitude toward the transportation system and a variety of potential messages about public transit, respondents were read the following script:

Allegan County Transportation has developed a five-year plan to improve transportation services for residents of Allegan County. It calls for dedicating service hours throughout Allegan County, providing rides to the senior meal sites and offering rides to the only dialysis clinic in the county. Then, respondents were randomly assigned to one of five experimental conditions.
1. This plan was created after conducting several meetings, surveys, and input sessions during the past two years with Allegan County residents like you.
2. This plan was created after conducting several meetings, surveys, and input sessions during the past two years with Allegan County community leaders.
3. This plan was created after conducting several meetings, surveys, and input sessions during the past two years with 1,000 Allegan County residents like you.
4. This plan was created after conducting several meetings, surveys, and input sessions during the past two years with 200 Allegan County community leaders.
5. No message.

After being read one of the messages above, respondents were asked to provide a response to the following: “Using a scale from 1 to 5, with 1 being strongly oppose and 5 being strongly support, please tell me what number best indicates your attitude toward the Allegan County Transportation Five-Year Plan.”

Table 1 lists the number of participants assigned to each experimental condition.

<table>
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<th>Participant Message Type</th>
<th>Number</th>
<th>Community Members</th>
<th>Community Leaders</th>
<th>Off-Set Control</th>
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<td>1,000 or 200</td>
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<td>122</td>
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<td></td>
</tr>
<tr>
<td>No Number</td>
<td>126</td>
<td>124</td>
<td>106</td>
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</table>

Next, respondents were told that the survey firm was collecting names of people who support public transportation to share with elected officials in their community. Respondents were told their name would not be connected to their survey responses in any way or sold to any other agency; it would be used only to share with elected officials. Then, the researcher asked whether he/she could add the respondent’s name to the list of public transit supporters. If the respondent said yes, he/she was asked for his/her first and last name. Finally, questions were asked about demographics (age, income, gender) so their effects could be controlled in the final analysis.

**Measures**

**Verbal Support for the Policy**

Verbal support for the policy was measured with a five-point Likert scale (1 = “strongly oppose,” 5 = “strongly support”). The item asked, “What number best
indicates your attitude toward the Allegan County Transportation Five Year Plan?” Higher scores reflected more positive support for the policy (M = 3.82, SD = 1.07).

**Behavioral Support for the Policy**

Behavioral support for the policy was measured categorically. Respondents were asked to add their name to a list of public transportation supporters to be shared with their local elected officials. Respondents agreeing to share their name were coded as 1, all others as 0 (59% agreed to share their name).

**Participation Messages**

First, we wanted to compare the effect of “people like you” messages and “community leaders” messages to the control group. In this case, the control message was coded as 1. Two dummy variables were created. The “people like you” messages (“people like you” and “1,000 people like you”) were coded as 0. Also, the “community leaders” messages (“community leaders” and “200 community leaders”) were coded as 0.

Next, we wanted to compare the effect of “people like you” messages to “community leaders” messages. Therefore, “people like you” messages (“people like you” and “1,000 people like you”) were coded as 1. Two dummy variables were created. The “community leaders” messages (“community leaders” and “200 community leaders”) were coded as 0. The “no message” control group was coded as 0.

Finally, we wanted to compare the effect of individual messages. The control group was coded as 1. The “people like you,” “1,000 people like you,” “community leaders,” and “200 community leaders” conditions were each coded as 0.

**Gender**

A dummy variable for gender was created. Female participants were coded as 1; male participants were coded as 0 (female = 65.5%, N = 600).

**Age**

Age was an ordinal variable but was treated as a continuous variable for purposes of analysis. Categories included ages 18–24, 25–30, 31–49, 50–65, and 65+ (N = 591).

**Income**

Respondents were asked to report their annual household income for 2008. Income was an ordinal variable but was treated as continuous for purposes of
analysis. Categories included less than $25,000 per year, $25,001–$50,000 per year, $50,001–$75,000 per year, and $75,000+ per year (N = 479).

**Involvement**
A dummy variable was created for involvement. Respondents were asked, “Have you or anyone you know who lives in Allegan County had an unmet transportation need in the past 12 months?” Respondents indicating a positive response were considered involved and coded as 1; all others were deemed uninvolved and coded as 0 (involved = 21.5%, N = 587).

**Results**
Multiple regression was used to analyze the effect of these messages on verbal support for the policy. Table 2 provides the results. The analysis showed that the “people like you” messages were a statistically significant negative predictor ($\beta = -0.12$, $t = -1.99$, $p = .047$) of verbal support for the policy compared to the “no message” condition. While “community leader” messages had a negative effect on verbal support for the policy ($\beta = -0.01$, $t = -0.13$, $p = .90$), this result was not statistically significant and was close to zero. Thus, the data were not consistent with hypothesis 1a; however, the data were consistent with hypothesis 1b. The data demonstrated that messages indicating similar others participated in developing a transportation policy significantly decreased support for the policy. Additionally, the data were not consistent with either hypothesis 2a or 2b. That is, messages indicating that community leaders participated in developing a transportation policy did not significantly affect support for the policy.

Next, the effect of participation messages was tested on people’s behavioral support for the policy. Again, behavioral support for the policy was measured by whether the respondent added his name to the list of transit supporters to be shared with local elected officials. Hypotheses 1a, 1b, 2a, and 2b were tested using logistic regression. Table 3 provides the results. Compared to the control, none of the messages had a significant effect on behavioral support for the policy. However, the “community leaders” message showed an effect near significance ($p = .07$). Holding the remaining variables at their modal values, the “community leaders” message increased the probability of providing one’s name by 11 percent compared to the control group, providing qualified support for hypothesis 2a. The remaining messages did not have an effect on providing one’s name to the list of transit supporters.
### Table 2. OLS Regression Results for Effect of Combined Messages on Verbal Support

<table>
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<th>Variable</th>
<th>( b )</th>
<th>s.e.</th>
<th>( \beta )</th>
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<td>Participation messages (Baseline = no message)</td>
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</tr>
<tr>
<td>“Community leaders” message</td>
<td>-.02</td>
<td>.13</td>
<td>-.01</td>
</tr>
<tr>
<td>“People like you” message</td>
<td>-.26*</td>
<td>.13</td>
<td>-.12</td>
</tr>
<tr>
<td>Female</td>
<td>.28**</td>
<td>.10</td>
<td>.13</td>
</tr>
<tr>
<td>Age</td>
<td>.14**</td>
<td>.05</td>
<td>.13</td>
</tr>
<tr>
<td>Income</td>
<td>-.02</td>
<td>.05</td>
<td>-.02</td>
</tr>
<tr>
<td>Involved</td>
<td>.61***</td>
<td>.11</td>
<td>.25</td>
</tr>
<tr>
<td>Constant</td>
<td>3.20***</td>
<td>.29</td>
<td></td>
</tr>
</tbody>
</table>

\( F = 9.24*** \)

\( \text{Adj. } R^2 = .10 \)

\( N = 455 \)

*p<.05; **p<.01; ***p<.001

### Table 3. Logistic Regression Results for Effect of Specific Messages on Behavioral Support

<table>
<thead>
<tr>
<th>Variable</th>
<th>( b )</th>
<th>s.e.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Participation messages (Baseline = no message)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>“Community leaders” message</td>
<td>.51</td>
<td>.28</td>
</tr>
<tr>
<td>“People like you” message</td>
<td>-.03</td>
<td>.02</td>
</tr>
<tr>
<td>Female</td>
<td>-.18</td>
<td>.21</td>
</tr>
<tr>
<td>Age</td>
<td>.25*</td>
<td>.11</td>
</tr>
<tr>
<td>Income</td>
<td>-.03</td>
<td>.10</td>
</tr>
<tr>
<td>Involved</td>
<td>1.43***</td>
<td>.29</td>
</tr>
<tr>
<td>Constant</td>
<td>-.73</td>
<td>.61</td>
</tr>
</tbody>
</table>

\( \text{Log Likelihood} = -289.19 \)

\( N = 468 \)

*p<.05; **p<.01; ***p<.001
Finally, although specific hypotheses were not proposed, we were interested in determining the comparative effects of the “people like you” versus “community leaders” messages. “Community leaders” messages had a greater effect than “people like you” messages \((t = 2.35, p = .02)\) on verbal support for the policy. Additionally, “community leaders” messages had a greater effect on behavioral support for the policy. The probability of adding one’s name to a list of policy supporters increased by 12 percent for those exposed to the “community leader” message compared to the “people like you” messages \((p = .015)\).

Discussion

This study involved a survey experiment at the conclusion of a year-long participatory process that engaged community citizens and leaders. Whose participation do citizens value most—citizens or community leaders? The results of the study suggest that people do not want “people like them” to develop policies on issues such as public transportation.

In fact, knowing that “people like you” developed a policy actually caused verbal support for the policy to decrease. This result aligns with Goethals and Nelson’s (1973) findings that similarity may actually result in adverse consequences. When the public believes they are not knowledgeable about the topic, knowing that similar others participated in policy development can cause support for the policy to decrease.

Also, the analysis found that messages emphasizing community leader participation resulted in more policy support than those emphasizing participation by similar others. This finding supports Kweit and Kweit’s (2007) results that perceptions of participation (by community leaders) may have more desirable outcomes than actual participation. At first blush, this finding appears counter to participatory theorists who posit the many benefits of citizen engagement.

However, these findings may not discredit the value of participatory processes, but rather provide data that suggest conditions under which publicity of these processes could garner additional citizen support. Deliberative processes, such as citizen juries, bring community members together, provide them with background facts and myriad arguments, and create dedicated discussion and collaborative dialogue for an extended period. In essence, the citizens who participate leave the process with more expertise than when they arrived—creating citizens who are likely more knowledge about the particular policy than their peers. These results
suggest that policies developed through these types of citizen engagement processes must make clear to the public that citizen experts assisted in policy development. Merely knowing that participation by the public occurred is not sufficient and can result in adverse consequences such as decreased policy support.

Recent work on attitudes toward democratic decision-making suggests that citizens have a number of negative attitudes about elites; at the same time, citizens have considerable ambivalence about citizen participation in policy-making (Hibbing and Theiss-Morse 2002). The findings in this paper provide evidence that citizens prefer elites to handle decision-making on policies that involve both technical elements and some value judgments. People want those with knowledge to make policy decisions on issues for which they do not possess expertise. They do not want “people like them,” without knowledge, to make uneducated decisions. When citizens believe people like them participated in policy-making on local issues (like public transportation), policy support may actually decrease.

Yet, many public engagement processes, including the one in Allegan County, do not limit participation to only elites or the public. Oftentimes, these processes engage both groups, seeking to involve a diverse range of people and perspectives in policy-making. In the current experiment, we studied only the effect of knowing that either similar others or elites participated in policy-making on support for the policy. Perhaps, messages emphasizing that a diverse group of citizens and elites had the opportunity to participate in policy-making would increase support for the policy and the legitimacy of the process. These messages would indicate the true nature of the processes that usually occur in participatory transit planning. Future research could address this possibility by testing messages that include both citizens and elites.

Media coverage could also affect perceptions of participation. Because this study received little newspaper coverage (i.e., two articles total, one per local paper) two months before this experiment occurred, it is unlikely the media affected perceptions of the public involvement processes that occurred prior to this study. However, for other public transit involvement efforts, it is possible that media coverage could shape public perceptions (see Dearing and Rogers 1996; Iyengar and Kinder 1987; McCombs and Shaw 1972 for a discussion of agenda setting). That is, media coverage could affect perceptions of who and how many participated, whether these individuals were knowledgeable, and the extent to which all citizens had the opportunity to voice their opinions. Future research could assess the effect of how
participatory efforts are framed by the media on resulting public support for the policy.

Finally, we believe there is a possibility that having the opportunity to participate may increase support prospectively and decrease it retrospectively. That is, there may be a difference between having the opportunity to participate in the future and knowing that similar others had the opportunity to participate in the past. For example, if I have the opportunity to participate in the future, I may choose to participate and influence the outcome. In this case, I may like the policy better because I like the opportunity to participate generally. However, if I know only that people had the opportunity to participate in the past (as was the case in the current study), I can no longer influence the outcome. Also, when I know that non-policymakers, like me, have designed the policy, my support may be lower than it would have been if policymakers had designed the policy. The difference between prospective and retrospective opportunity to participate warrants future testing. However, the implication for transit professionals is to consider that, given the current study, retroactive opportunity can have negative consequences for support of the policy. There is still the possibility that proactive participation can increase support for the policy.

**Conclusion**

This study provided one of the few survey experiments conducted in the context of an actual transportation campaign on the effects of participation messages on support for an actual policy. The results provide further evidence about the conditions under which participatory messages may be influential as well as some of the limitations of perceptions of participation. Future studies may consider the following to improve on the limitations in this study.

First, this study occurred in a single rural county. The same results may not hold in a different state or type of area, such as an urban community. Therefore, replication in different types of communities would increase the external validity of the results.

Second, a couple of assumptions were made in this study. First, we assumed citizens are not knowledgeable about public transit issues. Second, we assumed citizens do not feel that they possess the expertise to develop transit policies. Future studies might consider a more rigorous test of these assumptions.
Third, the messages tested in this study were limited to the distinction between similar others and community leaders. However, many participatory processes may engage both. Additionally, at the core of deliberative processes is the effort to engage a range of different citizens. Therefore, future studies may seek to develop a variety of messages to test whether emphasizing other types of dissimilarity are effective at eliciting citizen support for policies.

Finally, our study employed a retrospective message. That is, we informed people that similar others had participated in policy-making. This retrospective message removed the opportunity for future participation from those who we contacted. Perhaps, our findings of decreased policy support hold true only for retrospective messages. If so, messages that provide people with an opportunity to voice their opinions may be effective in increasing support for transit policies. The important implication for transit professionals is the timing and framing of such messages. Those that promote retrospective participation should emphasize community leader participation and those promoting prospective participation need to be tested.

We have found that who participates matters. Citizens do not want “people like them” developing policies. Transit professionals should be cautious when promoting deliberative and participatory processes. Messages focusing on similarity alone could have a boomerang-type effect by decreasing support for public policies.

Rather, transit professionals should develop messages that emphasize the knowledge or expertise of those involved in participatory processes. In addition, it is possible that citizen’s would find value in knowing that they had the opportunity to participate, given Kweit and Kweit’s (2007) findings; however, the extent to which transit professionals promote this engagement should be attempted with caution until the nuances of how to design the messages receive further testing.

At the very heart of participatory transit planning are democratic ideals of giving citizens a voice in determining public services that will best meet community needs. As transit professionals know, engaging the public in participatory processes requires extensive resources. Maximizing the efficiency and effectiveness of these efforts becomes important as transit agencies seek to garner public support for the plans that result from these participatory processes. This study suggests that promoting the participation and contribution of elites is critical to securing public support of transit plans once they have been developed.
Endnotes

1 It is possible that some individuals may prefer not to engage in policy-making themselves, yet want the opportunity to be involved. However, we believe that these individuals would support a policy by knowing that the general public was encouraged to participate because they, as members of the general public, had the opportunity to provide input. However, our findings reveal that knowing members of the community participated in policy-making actually decreased support for the policy—suggesting that, while some people may fall into the category of not wanting to participate but wanting the option, the majority of people prefer to have elites, or knowledgeable others, engage in policy-making on their behalf for issues such as public transportation.

2 We also explored a second independent variable: number of participants (200 or 1,000 v. no number). We acknowledge this creates an ecological confound in the design, as the number of participants in the messages is not kept constant. In the community leader by number of participants condition, the message referred to 200 community leaders who participated in policy development. However, in the community member by number of participants condition, the message referred to 1,000 community members who participated in policy development. While this inconsistency is not ideal, the study was part of a larger transit project in a community, and the design used the actual numbers of different types of participants. Since 1,000 community leaders did not participate in the process, it would be unethical to report this number, and vice versa.

3 No major statistical differences were found between the control group and individual messages on dependent variables.

4 After conducting an archive search for articles covering the public involvement processes that occurred, only one article in each paper was found. These two articles discussed the input sessions in Phase 3 and appeared in September 2009. Because the media coverage of the public engagement processes prior to the current survey was limited, the public was unlikely affected by the media, allowing the manipulation to have stronger effects.

5 The control condition allowed assessment of any previous question effects.

6 An additional analysis of the individual messages found that only the “people like you” message ($\beta = -.12, t = -2.03, p = .04$) was a significant negative predictor of verbal support for the policy compared to the control group, while the “1000 people like you” message ($\beta = -.08, t = -1.42, p = .16$), the “community leader” message ($\beta =$
.05, $t = 0.91, p = .36$), and the “200 community leaders” message ($\beta = -.07, t = -1.14, p = .26$) were not, controlling for other covariates in the model.

References


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Making a Successful LRT-Based Regional Transit System: Lessons from Five New Start Cities

Gregory L. Thompson and Jeffrey R. Brown
Florida State University

Abstract

This paper examines five metropolitan areas where light rail transit (LRT) lines serve as regional transit backbones. The paper defines a successful LRT-based regional transit system as one with high riding habit and productivity for all combined modes in each metropolitan area, and as also having high LRT ridership and productivity. Based on these criteria, Portland emerges as a successful LRT-based regional transit system. Our analysis reveals three characteristics that explain the Portland transit system’s strong performance: the network’s dispersed nature, the overlay of a higher-speed, high-frequency regional LRT network atop the local bus system, and the use of transfers to provide passengers easy access to a diverse array of destinations. We examine the performance of all five metropolitan areas with respect to these characteristics using a combination of agency data and insights from interviews with key informants.

Introduction

A new era of transit development began in 1981 when San Diego, a city whose transit system contained only buses, opened its first regional light rail transit (LRT) line. Since then, 11 other U.S., previously bus-only metropolitan areas opened their own LRT lines. Several of these new LRT lines have become the backbones of
metropolitan transit systems, carrying a large share of the metropolitan area’s total transit ridership. In this paper, we examine transit performance in five such metropolitan areas, with the objective of identifying whether system design characteristics influence performance. Using Portland as the model of a successful transit system, we identify three characteristics that are associated with Portland’s success. These characteristics are the transit network’s dispersed nature, the overlay of a higher-speed, high-frequency regional LRT network atop the local bus system, and the use of transfers to provide passengers easy access to a diverse array of destinations. We examine the degree to which the incidence of these characteristics is correlated with positive transit performance in the other four systems: Dallas, Sacramento, Salt Lake City, and San Diego. We find that better metropolitan transit performance is associated with a greater incidence of the three characteristics. We conclude by discussing the implications for planners in designing successful metropolitan transit networks.

Literature Review

Scholars examining the performance of LRT have typically looked at the mode as a stand-alone entity rather than as a component of an integrated transit system and/or have tended to emphasize the role of non-transit factors such as urban structure and land use policy as important contributors to ridership and performance. Scholars writing on the first subject tend to compare LRT to bus in terms of ridership, cost, and productivity and usually find LRT deficient (Kain 1998; Moore 1993). Scholars writing on the second subject tend to emphasize the role that strong CBDs and transit-oriented development (TOD) land use strategies play in leading to higher ridership or larger transit commute mode shares (Bernick and Cervero 1997; Cervero 2007; IURD et al. 2004). These two literatures tend to be quite distinct, with little connection between them. However, one characteristic they largely have in common is a tendency to ignore the role that LRT might play in the context of a regional transit system.

There is, however, a small but growing literature that emphasizes the role that rail transit, either LRT or heavy rail, can play as a trunk line (or backbone) in an integrated bus-rail regional system. Vuchic (2005) discusses the use of LRT as the backbone of a regional system that embraces a family of interconnected modes. Brown and Thompson (2009) found that successful rail metropolises use rail as the backbone of a multi-destination network that is structured to provide access to important destinations throughout the region. They insist that comparisons of bus
versus rail performance have been clouded by a failure to consider the variety of roles these two modes actually play. They find that rail is a stronger performer in terms of ridership and productivity, both for itself and the regional transit system as a whole, because it serves as the backbone of an integrated system whereas express bus-based services tend to be isolated due to the desire to provide one-seat rides. Thompson and Matoff (2003) found similar results in their study of multi-destination versus radial transit systems in nine metropolitan areas. Bruun’s work provides additional support for all these findings (2007). This paper extends this line of inquiry by seeking to understand the causes of variation in transit performance in five metropolitan areas in which LRT serves as the regional transit backbone.

Data and Methodology
We examined the performance of LRT-based regional transit systems in five U.S. metropolitan areas in 2006 where LRT accounts for 30 percent or more of total metropolitan area transit ridership (measured on a passenger miles basis): Dallas, Portland, Sacramento, Salt Lake City, and San Diego. Each of these metropolitan areas is centered on a city that implemented LRT as part of a previously bus-only transit system since 1981. The five metropolitan areas have populations between two million and six million (U.S. Census Bureau 2008).

Our method involves documenting the performance of each metropolitan area’s transit system in order to identify the most successful system. We then examine that system to determine which characteristics account for its success. We use the identified characteristics as transit network design criteria and evaluate how well each metropolitan area scores on these criteria. This scoring system serves as a hypothetical explanation for the variation in regional transit performance among the five metropolitan areas. We hypothesize that higher total scores on the set of design criteria will be associated with higher overall transit performance.

A metropolitan area’s transit system consists of the aggregation of all fixed-route services in the metropolitan area. We measure system performance 1) by examining riding habit (passenger miles per capita) and productivity (passenger miles per revenue mile) at a metropolitan scale for all fixed-route modes and 2) by examining LRT ridership (passenger miles) and productivity (passenger miles per revenue mile). We construct metropolitan scale measures of riding habit and productivity by identifying all transit agencies in each metropolitan area that provide fixed-
route service and aggregating the fixed-route ridership and service statistics to produce metropolitan totals. We do not consider vanpool or demand responsive services in this analysis.

Our analysis uses a combination of quantitative and qualitative data. We obtained ridership (passenger miles) and service (revenue miles) data from the National Transit Database using the Florida Department of Transportation’s (FDOT) web-based data extraction tool (FDOT 2008). We obtained population data from the U.S. Census Bureau (2006). Using these data, we calculated riding habit (passenger miles per capita) and productivity (passenger miles per revenue mile) for the combination of all transit agencies providing fixed route service in each metropolitan area. We also obtained mode-specific ridership (passenger miles) and service (revenue miles) for LRT and for the total of all fixed-route bus service in each metropolitan area (FDOT 2008). We used these data to construct mode-based productivity measures (passenger miles per revenue mile) and to calculate the percent of all ridership and service provided by each mode. For Dallas and San Diego, we obtained commuter rail statistics, which we report for completeness.

We also obtained data from individual agencies about passenger activity (by mode, by station/stop, and in some cases, by time of day and direction) for some study areas. We obtained geographic information system (GIS) shapefile data that we used to construct maps of the regional transit systems in each metropolitan.

We provided context for these data by drawing on information gained in interviews with key informants in each metropolitan area. The key informants are individuals with a long-range perspective on bus and light rail transit development. These interviews provide information about the regional transit vision, the role the agency hoped that light rail and bus transit would play within this vision, the present-day operation and passenger use of the transit system, and other insights about systems planning.

**Transit Performance in Five LRT New Start Cities**

In evaluating the performance of each metropolitan area’s LRT-based regional transit system, we considered both individual mode and total regional performance. We judged a regional transit system to be successful if it met four criteria: high metropolitan area riding habit, high metropolitan area service productivity, high LRT ridership, and high LRT productivity. Metropolitan area riding habit refers to the total number of passenger miles consumed on all fixed-route transit modes in
the metropolitan area expressed on a per-person basis (passenger miles per capita). Metropolitan area service productivity refers to the number of passenger miles per revenue mile for all fixed-route modes in each metropolitan area. LRT ridership refers to the number of passenger miles traveled by LRT patrons. LRT service productivity refers to the number of passenger miles per revenue mile for LRT service.

Table 1 provides mode-based and metropolitan area ridership and productivity statistics. The top panel reports LRT ridership, service, and productivity information and expresses LRT ridership and service as percentages of all fixed-route service in each metropolitan area. The panel shows that LRT ridership and service are highest in Portland and San Diego, followed by Dallas. Sacramento and Salt Lake City have much lower LRT ridership and provide much less bus and LRT service than the other three metropolitan areas. In each of the five metropolitan areas, LRT ridership accounts for 30 percent or more of the entire metropolitan area’s transit ridership. The LRT ridership shares range from a low of 30 percent in Dallas to a high of 54 percent in Salt Lake City. LRT service accounts for a much smaller percent of the metropolitan area total than LRT contributes to ridership. LRT accounts for between 13 percent (Dallas) and 27 percent (Sacramento) of metropolitan area transit service. Thus, LRT is carrying a disproportionate share of metropolitan transit ridership, as one would hope. The far right column of the top panel reports LRT productivity. The most productive LRT service is in Salt Lake City, followed by Portland. Sacramento’s LRT system has the lowest productivity.

The middle panels provide the same information about commuter rail services (where applicable) and fixed-route bus service. Particularly striking are the differences in bus route productivity in the five metropolitan areas. Portland has much higher bus productivity (10.32 passenger miles per revenue mile) than the other metropolitan areas. Dallas ranks second, and San Diego is not too far behind. Salt Lake City has the lowest bus productivity (4.34 passenger miles per vehicle mile) of the five metropolitan areas.

Figure 1 provides a capsule history of bus and LRT ridership over the two decades preceding the data shown in Table 1. Each metropolitan area is shown as a graph panel. The panels all feature the same scale (expressed as millions of passenger miles) and cover the same time period (1984–2006). Bus ridership is shown on top of LRT ridership in each graph.
Table 1. Transit Agency Performance in Five LRT New Start Cities (2006)

<table>
<thead>
<tr>
<th>Metropolitan Area</th>
<th>Agency</th>
<th>Ridership</th>
<th>Service</th>
<th>Productivity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Passenger Miles</td>
<td>% of Metro Area Fixed-Route Total</td>
<td>Revenue Miles</td>
</tr>
<tr>
<td><strong>Light Rail Transit</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dallas</td>
<td>DART</td>
<td>136,797,106</td>
<td>30%</td>
<td>5,096,186</td>
</tr>
<tr>
<td>Portland</td>
<td>Tri-Met</td>
<td>179,875,394</td>
<td>39%</td>
<td>6,377,513</td>
</tr>
<tr>
<td>Sacramento</td>
<td>RT</td>
<td>78,181,014</td>
<td>50%</td>
<td>3,888,222</td>
</tr>
<tr>
<td>Salt Lake City</td>
<td>UTA</td>
<td>86,039,042</td>
<td>54%</td>
<td>2,827,710</td>
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<tr>
<td>San Diego</td>
<td>SDTI</td>
<td>208,875,499</td>
<td>44%</td>
<td>8,180,189</td>
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<tr>
<td><strong>Commuter Rail</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dallas</td>
<td>TRE</td>
<td>33,023,714</td>
<td>7%</td>
<td>1,087,437</td>
</tr>
<tr>
<td>San Diego</td>
<td>NCTD</td>
<td>42,970,414</td>
<td>9%</td>
<td>1,298,922</td>
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<tr>
<td><strong>Fixed-Route Bus Service</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dallas</td>
<td>DART, The T, DCTA</td>
<td>283,748,664</td>
<td>63%</td>
<td>32,591,274</td>
</tr>
<tr>
<td>Portland</td>
<td>CC, Tri-Met, Unitrans, RT, Yolo, Roseville</td>
<td>276,834,579</td>
<td>61%</td>
<td>26,821,806</td>
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<td>Sacramento</td>
<td>RT</td>
<td>79,388,437</td>
<td>50%</td>
<td>10,758,943</td>
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<td>Salt Lake City</td>
<td>UTA</td>
<td>72,567,090</td>
<td>46%</td>
<td>16,732,379</td>
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<td>San Diego</td>
<td>CVT, MTS, NCT, NCTD</td>
<td>226,843,780</td>
<td>47%</td>
<td>27,846,175</td>
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</table>

<table>
<thead>
<tr>
<th>Metropolitan Area Fixed-Route Transit (Total)</th>
<th></th>
<th>Passenger Miles</th>
<th>% of Metro Area Fixed-Route Total</th>
<th>Revenue Miles</th>
<th>% of Metro Area Fixed-Route Total</th>
<th>Passenger Miles per Revenue Mile</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dallas</td>
<td>All</td>
<td>453,569,484</td>
<td>38,774,897</td>
<td>11.70</td>
<td></td>
<td></td>
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<tr>
<td>Portland</td>
<td>All</td>
<td>456,709,973</td>
<td>33,199,319</td>
<td>13.76</td>
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<tr>
<td>Sacramento</td>
<td>All</td>
<td>157,569,451</td>
<td>14,647,165</td>
<td>10.76</td>
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<td></td>
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<tr>
<td>Salt Lake City</td>
<td>All</td>
<td>158,606,132</td>
<td>19,560,089</td>
<td>8.11</td>
<td></td>
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</tr>
<tr>
<td>San Diego</td>
<td>All</td>
<td>478,689,693</td>
<td>37,325,286</td>
<td>12.82</td>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Metropolitan Area Riding Habit</th>
<th>Population</th>
<th>Passenger Miles per capita</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dallas</td>
<td>6,003,967</td>
<td>75.54</td>
</tr>
<tr>
<td>Portland</td>
<td>2,137,565</td>
<td>213.66</td>
</tr>
<tr>
<td>Sacramento</td>
<td>2,067,117</td>
<td>76.23</td>
</tr>
<tr>
<td>Salt Lake City</td>
<td>2,039,542</td>
<td>77.77</td>
</tr>
<tr>
<td>San Diego</td>
<td>2,941,454</td>
<td>162.74</td>
</tr>
</tbody>
</table>

*Source: FDOT (2008), U.S. Census Bureau (2008).*
Two things stand out in these graphs. First, there is a sizeable difference in the magnitude of ridership among the five metropolitan areas. Ridership in Dallas, Portland, and San Diego is large and roughly comparable, although the metropolitan areas are different in terms of their total populations, leading to different riding habits, as discussed below. Ridership is much lower in Sacramento and Salt Lake City, although their populations are not very different from that of Portland. These two metropolitan areas historically have provided much less service per capita.
than the others. This fact can also be seen in the service statistics (revenue miles) for both metropolitan areas’ LRT and fixed-route transit total reported in Table 1.

Second, the recent ridership increases experienced in all the cities appears to be due almost entirely to increased LRT ridership. LRT ridership has increased steadily in Dallas, Portland, Sacramento, and Salt Lake City. San Diego has also experienced a general increase in LRT ridership, although it has experienced two periods of retrenchment. Bus ridership is flat or declining in all five cities.

The other gauges of transit performance are metropolitan area service productivity and riding habit. The far right column in the fourth panel of Table 1 reports overall transit productivity for the five metropolitan areas. In 2004, fixed-route service productivity for the U.S. (excluding New York City, which alone accounts for 40 percent of all U.S. transit ridership) was 11.1 passenger miles per revenue mile (FDOT 2008). All the metropolitan areas except Sacramento and Salt Lake City had productivity above this number in 2006. Among the five metropolitan areas, Portland stands out with the highest productivity, followed by San Diego and Dallas.

The bottom table panel reports metropolitan area population and riding habit (passenger miles per capita). Riding habit adjusts ridership for population differences among the metropolitan areas. In 2004, riding habit for the U.S. (excluding New York City) was 99 passenger miles per capita (FDOT 2008). Two of the five metropolitan areas have 2006 riding habit higher than this number: Portland and San Diego. Portland stands out with significantly higher riding habit (213.66 passenger miles per capita) than second-ranked San Diego (162.74 passenger miles per capita). Dallas and Sacramento ranked at the bottom in metropolitan area riding habit and near the bottom in productivity.

Despite its high LRT productivity noted earlier, Salt Lake City falls at or near the bottom both in terms of overall riding habit and productivity. Salt Lake City’s LRT line performs well by itself, but the bus service has very low productivity (4.34 passenger miles per bus mile), partly because the LRT line pulls so many riders away from the buses, as discussed later in the paper.

Based on the transit performance statistics shown in Table 1, Portland emerges as the most successful of the five metropolitan areas. It ranks first in metropolitan area riding habit and service productivity, which are the gauges of overall transit performance. Its LRT system ranks second to San Diego in ridership and second to Salt Lake City in productivity. Portland thus emerges at or near the top in the four measures we proposed to evaluate the performance of LRT-based regional transit systems.
Three Characteristics of Successful LRT-Based Regional Transit Systems

So why is Portland so successful? Many scholars would point to the importance of land use policies in Portland that encourage more compact development and the proliferation of transit-oriented developments as fundamental to the success of the metropolitan area’s transit system. While these factors undoubtedly contribute to Portland’s transit ridership on the margin, the fact is that Portland’s regional employment is decentralized like that in the other regions studied here. In 1970, employment in Portland’s CBD stood at 30,000 jobs and represented 7.0 percent of the metropolitan area’s total employment. Twenty years later, and four years after the first light rail line opened, CBD employment stood at 95,734 jobs, or 10.9 percent of the metropolitan total. From then until now, CBD employment has remained flat, while total metropolitan employment has continued to grow. In 2005, CBD employment stood at 96,877 jobs, or 7.8 percent of the metropolitan total. Despite the decline in relative CBD importance between 1990 and 2005, Portland’s transit system has increased its ridership and improved its productivity.

Our previous research identifies three important characteristics of Portland’s transit system associated with its success (Brown and Thompson 2008). First, Portland has a dispersed transit network. A dispersed transit network is one structured to serve an array of major destinations throughout the entire metropolitan area, as opposed to one in which service is concentrated on a single major destination (usually the CBD) and/or constrained to serve merely a portion of the metropolitan area. Portland’s dispersed transit network predates LRT development, which has been able to tap into its existence.

Second, Portland uses LRT to provide a high-speed regional service overlay atop the local bus system. A high-speed regional overlay is higher-speed, high frequency service that lies atop the local network and works with it to allow travelers to quickly reach the wide array of major destinations throughout the metropolitan area. Portland’s combined bus-rail network provides relatively quick travel between the metropolitan area’s activity centers, and this makes transit more attractive to prospective riders.

Third, Portland relies on easy transfers between its bus and rail systems, as well as bus-to-bus transfers, to connect more destinations than would be possible with a system based on one-seat rides. Transfers are important evidence that passengers are taking advantage of integrated regional bus-rail transit systems to reach a wide array of regional destinations. Portland’s transit system exhibits a significant amount of transfer activity.
As a result of having these three design characteristics, Portland’s transit system attracts a large number of non-CBD riders. This is important given the emergence of many other activity centers in the Portland area. Collectively, the three system design characteristics and the evidence of large non-CBD ridership are hallmarks of a regional, LRT-based multidestination transit system.

We hypothesize that variation in transit performance discussed earlier can be explained by variation in the extent to which the three design characteristics are present in each metropolitan area’s transit system. We suspect that deficiencies with respect to these key characteristics as preventing the transit agencies in each metropolitan area from achieving higher ridership and productivity from their LRT-based regional transit systems.

We developed a five-point scoring system to measure the degree to which each of the three system design characteristics is present in each metropolitan area, including Portland. A score of 5 indicates that a design characteristic is fully present, while a score of 1 indicates that a characteristic is not present. Scores in between are assigned when a characteristic is largely (4), partially (3), or minimally (2) present. Table 2 provides the results of our scoring system. Portland and San Diego have the highest overall scores. Dallas and Sacramento have significantly lower overall scores. Salt Lake City has the lowest overall score. No metropolitan area receives a score of 5 on any characteristic, indicating that all metropolitan areas are deficient to one degree or another. These scores roughly correspond to the rankings of the metropolitan areas on the riding habit and service productivity measures reported at the bottom of Table 1.

Table 2. Evaluation Matrix: Four Characteristics of Successful LRT Systems

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Portland</th>
<th>San Diego</th>
<th>Dallas</th>
<th>Sacramento</th>
<th>Salt Lake City</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dispersed transit network</td>
<td>4</td>
<td>4</td>
<td>2</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>High-speed regional service overlay</td>
<td>4</td>
<td>4</td>
<td>3</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Utilizes transfers to reach many destinations</td>
<td>4</td>
<td>4</td>
<td>2</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Score</td>
<td>12</td>
<td>12</td>
<td>7</td>
<td>7</td>
<td>4</td>
</tr>
</tbody>
</table>

Evaluation Scores:  
5 Characteristic is fully present  
4 Characteristic is largely present  
3 Characteristic is partially present  
2 Characteristic is minimally present  
1 Characteristic is not present

In the text below, we explain how we arrived at the scoring assigned to each metropolitan area. We discuss each metropolitan area in the order presented in Table 2, beginning with Portland. Our discussion relies heavily on insights gained from
analyses of agency data and interviews with key informants in each metropolitan area. We also rely on Figure 2 as an important aid in our discussion of the system design characteristics. The figure provides maps of the metropolitan transit systems in each of the five metropolitan areas. The maps show local bus routes in a medium-gray color. The regional light rail transit routes are shown as a thick line atop the local bus routes on which circles (representing rail stations) are overlaid. The stops are generally spaced at one-mile intervals and often are designed to facilitate transfers between buses and trains and buses and buses as well as to provide auto access. Some stops provide planned pedestrian access to nearby destinations.

Figure 2. Regional transit system maps for five metropolitan areas
The regional light rail lines operate at scheduled speeds of 20 to almost 30 miles per hour compared to less than 12 miles per hour for local buses. Their headways generally are 15-minute or better. They thus represent a higher-speed, high-frequency type of service. In San Diego and Dallas, less frequent commuter rail services are shown as a narrow line with periodic cross lines. Figure 2 uses heavy black circles or arcs to indicate major regional employment centers not served by regional transit routes or not connected to them very well or at all by local bus routes.

**Portland**

We identified Portland as possessing a successful metropolitan transit system with all three design characteristics. But even Portland is deficient to a minor degree with respect to each characteristic, and hence we assigned it a score of 4 (characteristic is largely present) on each, for a total score of 12.

Portland largely possesses a dispersed transit network. The map panel at the upper right in Figure 2 indicates that Portland possesses a local bus network that covers the entire metropolitan area and thus attempts to serve all the major activity centers. While nearly half Portland’s bus routes serve the CBD, these routes serve many other destinations as well, and its most heavily patronized routes do not serve the CBD. They operate on major arterial roads characterized by strip commercial development. Portland’s bus and rail routes are integrated with each other by design, either by functioning in a grid, or through the use of timed-transfer centers. This service structure has prevailed since the late 1970s, several years before the introduction of the first LRT service in the region, but the bus restructuring was done with light rail in mind.

Portland’s light rail lines function as the higher-speed regional transit overlay and are evident in Figure 2. From the time the first line opened in 1986, the regional light rail lines provided the CBD link for many of the previously restructured bus routes in each light rail corridor. The light rail lines operate at a scheduled speed of about twice as fast as local buses and serve not only the CBD but major and growing employment centers to both the east and west. There still are many major employment centers not served by regional transit in Portland, as indicated by the circles in Figure 2. For this reason, Portland does not get a perfect score on this characteristic. However, all these employment clusters and corridors are served by local buses that connect with regional transit service.

As noted earlier, transfers are important evidence that passengers are taking advantage of integrated regional bus-rail transit systems to reach a wide array of
regional destinations. If transfer activity merely indicated forced shifting from one mode to another, we would expect to find high levels of transfer activity to be associated with stagnant or declining patronage transit systems. However, we find that high levels of transfer activity tend to be associated with strong and growing patronage systems.

Portland’s transit system illustrates the importance of transfers for successful regional transit system performance. Figure 3 shows average weekday LRT boardings by station in spring 2007. The stations with the highest numbers of boardings are major transfer centers, including the Cedar Hills, Beaverton, and Gateway timed transfer centers, Hollywood, Northeast 82nd Avenue, and Northeast 60th Avenue.

San Diego
We also identified San Diego as having a successful transit system (based on the discussion around Table 1). Like Portland, San Diego possesses all three design char-
acteristics. Also like Portland, it is deficient to at least a minor degree on each of the characteristics, and hence we also assigned it scores of 4 for an overall score of 12.

The bottom map panel in Figure 2 shows that San Diego’s transit coverage resembles Portland’s but it is even more decentralized. San Diego’s local bus network blankets the entire urbanized area. Although it is operated by numerous agencies, it and the various rail services are integrated by a centralized board into a cohesive network. A large percentage of bus routes terminate at light rail stations rather than continuing to the CBD as they did before the various light rail lines opened.

San Diego’s LRT system functions as the region’s high-speed service overlay. The light rail lines operate at much higher scheduled speeds than local buses and cover the major employment corridors in the south county. The west-east line running from Old Town to El Cajon (see Figure 2) does not serve the CBD but instead runs through the linear edge city area known as Mission Valley. As in Portland, San Diego’s regional transit overlay is not perfect. Several corridors containing heavy and growing employment extend north of the Mission Valley, indicated as the I-15, I-5, S.R. 78, and Sorrento Valley (S.R.) corridors in Figure 2. The I-15 corridor is served by a complex network of express buses that extend from Escondido to the San Diego CBD. Some of these buses provide non-stop service from northern neighborhoods to the San Diego CBD. Others leave the freeway to stop at intermediate stops, including a major transfer station with the Mission Valley light rail line. The I-5 corridor has a similar pattern of express buses plus a commuter rail service that extends from Oceanside to the San Diego CBD, while also stopping at large employment concentrations and transfer connections at Sorrento Valley (S.R. on Figure 2), and Old Town. Service is fast but infrequent.

The service quality in these corridors is far lower than that in the light rail corridors. The bus and commuter rail services reach fewer intermediate destinations, have (in the case of bus) slower speeds to intermediate destinations, and offer much less frequent service. Whereas light rail corridors carry 25,000 to 50,000 daily passengers, the northern express bus and commuter rail corridors carry less than 6,000 daily passengers. (A regional light rail line opened in the State Route 78 corridor in March 2008, too late to affect the data in this paper.)

Like Portland, San Diego’s transit system relies heavily on transfers to allow patrons to reach widely dispersed destinations. Figure 4 displays passenger activity prior to the opening of the non-CBD-serving Mission Valley LRT line. The most heavily-patronized stops are those characterized by high transfer activity, including the region’s two most heavily-patronized stops (Old Town Transit Center and 12th and
Imperial Station). Half the top 20 transit stops in the region are major transfer centers, and nearly all these stops saw passenger activity increase between 2005 and 2006 (see Table 3). Most stops listed in the table with declining patronage between 2005 and 2006 are stops in the CBD. In January 2008, San Diego abolished free transfers as part of a budget balancing strategy. This poses serious challenges to a transit system whose structure is predicated on easy passenger transfer activity below Portland. The effects of this policy change on patronage will bear watching.

Figure 4. Passenger activity at San Diego rail stations and bus stops (2005)
### Table 3. San Diego Top 20 Transit Stops in Fiscal Year 2005 and 2006

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Old Town Transit Center</td>
<td>2</td>
<td>1</td>
<td>20,574</td>
<td>31,958</td>
<td>55.33%</td>
</tr>
<tr>
<td>12th and Imperial Station</td>
<td>1</td>
<td>2</td>
<td>20,639</td>
<td>21,858</td>
<td>5.91%</td>
</tr>
<tr>
<td>International Border Station</td>
<td>3</td>
<td>3</td>
<td>19,849</td>
<td>20,949</td>
<td>5.54%</td>
</tr>
<tr>
<td>Iris Avenue Trolley Station</td>
<td>4</td>
<td>4</td>
<td>14,977</td>
<td>15,431</td>
<td>3.03%</td>
</tr>
<tr>
<td>H Street Trolley Station</td>
<td>5</td>
<td>5</td>
<td>11,972</td>
<td>12,210</td>
<td>1.99%</td>
</tr>
<tr>
<td>5th Avenue Station - C Street</td>
<td>6</td>
<td>6</td>
<td>11,034</td>
<td>11,182</td>
<td>1.34%</td>
</tr>
<tr>
<td>El Cajon Transit Center</td>
<td>11</td>
<td>7</td>
<td>8,799</td>
<td>10,935</td>
<td>24.28%</td>
</tr>
<tr>
<td>Euclid Trolley Station</td>
<td>7</td>
<td>8</td>
<td>10,381</td>
<td>10,622</td>
<td>2.32%</td>
</tr>
<tr>
<td>City College Station</td>
<td>8</td>
<td>9</td>
<td>10,243</td>
<td>10,565</td>
<td>3.14%</td>
</tr>
<tr>
<td>Fashion Valley Trolley Station</td>
<td>10</td>
<td>10</td>
<td>9,347</td>
<td>10,072</td>
<td>7.76%</td>
</tr>
<tr>
<td>Palomar Street Trolley Station</td>
<td>9</td>
<td>11</td>
<td>9,988</td>
<td>9,483</td>
<td>-5.06%</td>
</tr>
<tr>
<td>Civic Center Station</td>
<td>12</td>
<td>12</td>
<td>8,351</td>
<td>7,644</td>
<td>-8.47%</td>
</tr>
<tr>
<td>24th Street Trolley Station</td>
<td>14</td>
<td>13</td>
<td>7,656</td>
<td>7,583</td>
<td>-0.95%</td>
</tr>
<tr>
<td>American Plaza</td>
<td>13</td>
<td>14</td>
<td>7,938</td>
<td>7,170</td>
<td>-9.67%</td>
</tr>
<tr>
<td>Escondido Transit Center</td>
<td>16</td>
<td>15</td>
<td>6,629</td>
<td>7,157</td>
<td>7.97%</td>
</tr>
<tr>
<td>San Diego State University</td>
<td>36</td>
<td>16</td>
<td>2,281</td>
<td>6,968</td>
<td>205.48%</td>
</tr>
<tr>
<td>Vista Transit center</td>
<td>15</td>
<td>17</td>
<td>6,477</td>
<td>6,794</td>
<td>0.70%</td>
</tr>
<tr>
<td>Park and Market Station</td>
<td>21</td>
<td>18</td>
<td>5,618</td>
<td>6,106</td>
<td>8.69%</td>
</tr>
<tr>
<td>E Street Bayfront Trolley Station</td>
<td>17</td>
<td>19</td>
<td>6,397</td>
<td>5,959</td>
<td>-6.85%</td>
</tr>
<tr>
<td>Oceanside Transit Center</td>
<td>18</td>
<td>20</td>
<td>6,162</td>
<td>5,546</td>
<td>-10.00%</td>
</tr>
</tbody>
</table>

*Source: SANDAG (2007)*

### Dallas

As noted earlier, Dallas’s transit system has not experienced the high ridership and high productivity enjoyed by either Portland or San Diego. Dallas’s regional transit system is more deficient with respect to each of the system design characteristics than either of the two metropolitan areas just discussed, with each of these characteristics being only either minimally or partially present.

As the map panel in Figure 2 indicates, the Dallas metropolitan area features a well-integrated, dispersed network of bus and regional light rail lines in its eastern third. In this area, a comprehensive network of local bus routes gradually has been restructured around two regional light rail lines that serve employment concentrations not only in the CBD but also to the north. The western third of the metropolitan area contains a traditional CBD-radial local and express bus system centered on the Fort Worth CBD. In the middle third of the metropolitan area, however, as well as to the north, lie major employment centers not served by any type of transit, as shown by circles in Figure 2.
In the eastern half of the Dallas metropolitan area, LRT functions as a high-speed service overlay. A commuter rail line connects the Dallas and Fort Worth CBDs. It connects with the hub of the Fort Worth bus system and with the Dallas light rail lines on the edge of the Dallas CBD but is not effectively connected to employment concentrations in between. Its low service frequencies also serve to prevent it from functioning as a high-speed, high-frequency service backbone. Because local buses do not blanket many of the important destinations in the Dallas metropolitan area, because the regional overlay is less developed than in either Portland or San Diego, and because not even hybrid express buses serve employment corridors not served by regional transit routes, we rank Dallas behind Portland and San Diego in its performance on both the dispersed transit networks and regional transit overlay characteristics.

Also in the eastern half of the Dallas metropolitan area, transfers between buses or bus and rail are used to extend the array of destinations that patrons can access. Transfers are also used to a much lesser degree in the Fort Worth area. However, the two parts of the regions are not well connected, potential transfer activity is thus reduced, and patrons are able to reach far fewer of the metropolitan area’s widely dispersed destinations.

Sacramento
Sacramento’s transit system has also not experienced the high ridership and high productivity enjoyed by either Portland or San Diego. Sacramento’s regional transit system is more deficient with respect to each of the system design characteristics than either of the two metropolitan areas just discussed, with each of these characteristics being only either minimally or partially present.

Sacramento is a metropolitan area that once possessed a transit system characterized by the design features seen in Portland and San Diego, but has retrogressed in recent years. Until 2000, Sacramento possessed a dispersed regional network in which bus and rail lines worked together to serve a wide array of major destinations within the metropolitan core county. But light rail extensions built since 2000 have been less well integrated into the regional transit system. The extension of a light rail line to the south was similar to San Diego’s first light rail line to San Ysidro in that it ran well to the west of the previously established spine of transit service. Unlike in San Diego, however, Sacramento failed to move bus transfer centers (one of which is serving a dying mall) from the old spine to the regional light rail line (see map panel in Figure 2). Unlike the spectacular patronage growth that San Diego
experienced on both its rail and bus services in its first light rail corridor, Sacramento has experienced only lackluster success for its south corridor.

Figure 2 also shows that the more recent extension of light rail to Folsom is similar to the Dallas commuter rail line running near areas of high employment without connections to the employment. Finally, employment clusters in Davis, Woodland, and Roseville are served by express bus service that is designed to take residents of those places to the Sacramento CBD but not to take residents from the rest of the region to employment in those centers. It should do both. Thus, there now exists in the Sacramento area significant destination concentrations that are unconnected to the transit network. We conclude that the Sacramento metropolitan area has only pieces of both a dispersed transit network and a high-speed regional overlay.

We see evidence of the importance of transfer activity in the part of the Sacramento areas where local bus services are integrated with regional rail services. In Sacramento the most heavily patronized LRT station is the 16th Street Transfer Station where patrons transfer between two LRT lines. Unfortunately, the lack of a truly dispersed regional network has served to reduce the amount of transfer activity that might otherwise take place if riders could reach the presently unserved major destinations.

**Salt Lake City**

Earlier, we noted that the LRT portion of the Salt Lake City transit system is performing very well, but that the transit system as a whole is not doing well due to the very poor performance of the bus system. Overall, Salt Lake City was the worst performing of the five metropolitan areas. Salt Lake City also came out ranked worse on the scoring matrix used in Table 2. It is important to note that our data depict transit in Salt Lake City before 2007 when it was organized closer to the radial archetype than the other four metropolitan areas in this paper. Beginning with a local bus route restructuring in 2007 and with the more recent inauguration of regional commuter rail service oriented to travel in both in-bound and out-bound directions, the transit system now appears to be decentralizing. What we describe is the period before 2007.

Then as now, the Salt Lake City metropolitan area contained three distinct sub areas: Ogden to the north, Salt Lake City in the middle, and Provo to the south. The Utah Transit Authority served the entire area, but before 2007 operated distinct CBD-focused transit systems in each of Ogden, Salt Lake City, and Provo. Freeway express buses connected Ogden and Provo to the Salt Lake CBD.
The map panel in Figure 2 focuses only on the Salt Lake City part of the region as it was before 2007, when the transit routes functioned as a CBD-radial system characterized by little integration between its bus services or between its rail and bus services. After the 19-mile light rail system opened in three phases between 1999 and 2003, about 70 percent of the bus routes in the Salt Lake area continued to serve the CBD. For these routes, bus and rail service competed with one another in providing patrons with service to the CBD. The rail line had a much higher scheduled speed than the local bus routes, though it may have had little advantage with express buses going to the CBD. Unlike express buses, however, it served employment centers located at several stations in the southern part of its route. When the north-south LRT line opened, some CBD express buses were discontinued or truncated into outer light rail stations. Some new east-west service was added to serve light rail stations. In general, though, these east-west services were under-developed, being afflicted by gaps in coverage, significant route deviations, and/or low frequency service.

In many respects the Salt Lake City system resembled Portland’s east side bus network prior to its restructuring. At one time, Portland had numerous parallel east-west bus routes that provided low-frequency service to the Portland CBD from the eastern suburbs. About 1983, Portland eliminated some east-west routes, added service to others, and added high-frequency north-south bus routes. When the LRT began operation in 1986, Tri-Met plugged it into this network as another east-west line. The recently added north-south bus lines became major feeders and distributors from light rail stations. At about its midway point, the light rail line served a major transfer stations where all of the parallel east-west bus lines bunched up to provide transfers between each other and with the light rail line.

If the 1983 and 1986 restructurings had not happened, LRT would have been a competitor with the CBD-focused, poor quality parallel bus routes that already were there, and there would have been no high quality bus routes intersecting the LRT at right angles. Portland would have enjoyed much less patronage than it has since experienced on both its LRT and bus routes. This undesirable situation resembles the pre-2007 condition in Salt Lake City. As a consequence, major employment centers to the east and west of the light rail line were inaccessible to it (see Figure 2). To reach these employment centers by bus, residents from most of the region had to ride into the CBD, transfer, and ride out again.

We rank Salt Lake City below Dallas and Sacramento on the dispersed transit network criterion, lower as well on the extensiveness of its regional route overlay...
(given the presence of at-best hybrid express bus service on the Ogden and Provo links, as well as the poor integration of the regional light rail line with buses), and lower for the minimal attention paid to transfer facilities. These deficiencies appear to be changing now but were present at the time of the study.

Comparison of Scoring Matrix with Transit Performance
Earlier, we defined a regional transit system as being successful if it met four criteria: high metropolitan area riding habit, high metropolitan area service productivity, high LRT ridership, and high LRT productivity. We hypothesized that the relative presence of the three system design characteristics found in Portland might explain the variation in overall transit performance among the five metropolitan areas. To evaluate this hypothesis, we compared the four performance measures reported in Table 1 with the total score for each metropolitan area reported in Table 2. We relied on a combination of visual inspection and the calculation of correlation coefficients to evaluate the hypotheses.

We found strong positive relationships between a metropolitan area’s score and its metropolitan area riding habit (0.89), metropolitan service productivity (0.94), and LRT ridership (0.90). These three findings serve as evidence in support of our hypothesis. The only unexpected finding was the weak negative correlation (-0.11) between LRT service productivity and metropolitan area score, which is due to Salt Lake City’s very high LRT service productivity. It is likely that even this high LRT productivity would be even higher were the system design characteristics we discuss in the paper more evident in the Salt Lake City metropolitan area, as we discuss in the text. Thus, on balance, we conclude that there is a relationship between these key system design characteristics and metropolitan transit performance in these five new-start LRT metropolitan areas.

One Result: High Non-CBD Ridership
An important indication that transit patrons are relying on transfers to use dispersed transit networks with high-speed regional overlays to reach dispersed destinations is the size and/or share of riders travelling to destinations outside the CBD. CBDs are in relative decline as employment centers and major transit destinations, so successful transit systems need to tap the non-CBD ridership market. Successful systems will thus have a high percentage of non-CBD-bound riders. We find evidence for this supposition among our study metropolitan areas.
Evidence on the importance of the non-CBD market in Portland can be found in individual bus route ridership statistics, as well as the transfer activity data shown in Figure 3 earlier. The north-south bus routes intersecting the LRT at the 82nd Avenue and Hollywood stations are respectively the most and second most heavily patronized bus routes in the Portland metropolitan area, far surpassing patronage on routes that serve the CBD. These two routes run along arterial roads and serve strip commercial development.

In San Diego, about 80 percent of all bus routes do not serve the CBD, and we can assume that most of their patrons are not headed to the CBD. This fact suggests that the very strong performance of transit in the San Diego region results to a large extent from non-CBD passengers who make use of the system. This conclusion is reinforced by noting that for the 20 percent of bus routes that do serve the CBD, most of their passengers are going to non-CBD destinations, as well (see Table 4). Two-thirds of LRT riders, 3/4 of local bus riders, 85 percent of express bus riders, and 2/3 of commuter rail riders on CBD-bound service in San Diego are not traveling to the CBD.

### Table 4. Destinations of Weekday AM Peak Transit Riders in Sacramento and San Diego

<table>
<thead>
<tr>
<th>Destination</th>
<th>Number of Alightings</th>
<th>Percent of All Alightings</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sacramento LRT Riders</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Downtown Sacramento LRT stations</td>
<td>4,813</td>
<td>37.44%</td>
</tr>
<tr>
<td>16th Street Transfer Station</td>
<td>1,453</td>
<td>11.30%</td>
</tr>
<tr>
<td>Other LRT Stations</td>
<td>6,590</td>
<td>51.26%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>12,856</td>
<td>100.00%</td>
</tr>
<tr>
<td><strong>San Diego LRT Riders</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inside San Diego CBD</td>
<td>6,687</td>
<td>33.97%</td>
</tr>
<tr>
<td>Outside San Diego CBD</td>
<td>13,000</td>
<td>66.03%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>19,687</td>
<td>100.00%</td>
</tr>
<tr>
<td><strong>San Diego Commuter Rail Riders</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inside San Diego CBD</td>
<td>670</td>
<td>31.65%</td>
</tr>
<tr>
<td>Outside San Diego CBD</td>
<td>1,447</td>
<td>68.35%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>2,117</td>
<td>100.00%</td>
</tr>
<tr>
<td><strong>San Diego Bus Riders Using CBD-serving Express Routes</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inside San Diego CBD</td>
<td>400</td>
<td>14.55%</td>
</tr>
<tr>
<td>Outside San Diego CBD</td>
<td>2,349</td>
<td>85.45%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>2,749</td>
<td>100.00%</td>
</tr>
<tr>
<td><strong>San Diego Bus Riders using CBD-serving Local Routes</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inside San Diego CBD</td>
<td>2,517</td>
<td>23.37%</td>
</tr>
<tr>
<td>Outside San Diego CBD</td>
<td>8,254</td>
<td>76.63%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>10,771</td>
<td>100.00%</td>
</tr>
</tbody>
</table>

Note: Sacramento data refer to 2007 and San Diego data to fiscal year 2006.
Sources: RT (2007), SANDAG (2007)
We see this phenomenon in Sacramento and Dallas, as well, but to a lower extent. This is perhaps to be expected given their lower performance in Table 1 and lower scores in Table 2. In Sacramento, more than 60 percent of LRT patrons use it to reach non-CBD destinations (see Table 4). It is only on Sacramento's Folsom LRT extension that there is little indication of ridership destined to suburban destinations. There are only a total of 225 morning peak passenger alightings per day at the last four stations on the Folsom extension, despite their being located near major employment centers. The lack of connecting bus service likely suppresses patronage at these stations. If such bus service existed, the Folsom light rail line likely would experience heavy ridership destined to employment at its outer end, similar to ridership that Portland enjoys on the outer ends of its light rail lines. Sacramento's LRT productivity would improve as a result.

In Dallas, 45 percent of afternoon boardings on the CBD-focused LRT system are made by passengers boarding in non-CBD locations. Clearly even the two limited networks in Sacramento and Dallas are being used heavily by non-traditional (i.e. non-CBD) riders. We have no data on passenger destinations for Salt Lake City, although the hybrid nature of its system suggests that it too carries sizeable non-CBD traffic to the university on its east-west LRT line and activity centers on its north-sought LRT line.

**Conclusion**

This paper identified three characteristics of the transit system in Portland that appear to explain its success in terms of high riding habit and productivity, and measured the extent to which these same characteristics are also present in four other new start cities where LRT carries 30 percent or more of all metropolitan area transit riders. In general, we find an association between metropolitan area transit performance, shown in Table 1, and the presence of these characteristics, as recorded in Table 2 and discussed in the text.

This work suggests a possible method for better planning regional transit services by setting forth attributes that these services need to possess in order to attract substantial ridership and thus obtain satisfactory riding habit and productivity. Future research should apply this framework to other metropolitan areas of different sizes or whose LRT systems are of different lineage to test the whether these propositions can be generalized.
Acknowledgments

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