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| | |
|---|---|
| David Anspacher<br>Asad J. Khattak<br>Youngbin Yim | The Demand for Rail Feeder Shuttles |
| Philip Bullock<br>Qingjian Jiang<br>Peter R. Stopher | Using GPS Technology to Measure On-Time Running of Scheduled Bus Services |
| Graham Currie | The Demand Performance of Bus Rapid Transit |
| Patrick DeCorla-Souza<br>William G. Barker | Innovative Public-Private Partnership Models for Road Pricing/BRT Initiatives |
| Sanjay K. Singh | Review of Urban Transportation in India |

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## CONTENTS

*Our troubled planet can no longer afford the luxury of pursuits confined to an ivory tower. Scholarship has to prove its worth, not on its own terms, but by service to the nation and the world.*

# The Demand for Rail Feeder Shuttles

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## Abstract

*Rail transit systems offer opportunities for travelers to avoid traffic congestion in large urban areas. This article explores the possibility of expanding access to existing rail transit systems through demand responsive shuttles. It examines demand for such an innovation in the San Francisco Bay Area where relatively good rail service already exists. Using survey data collected in a case study of one urban and one suburban neighborhood (N=800 individuals surveyed) served by the San Francisco Bay Area Rapid Transit agency, this article investigates the influence of several factors on people's willingness to use, pay for, and wait for the shuttles. The results indicate that a significant percentage of the surveyed population is willing to try the shuttle. Higher willingness to use the shuttle was associated with women, younger and elderly respondents, noncommuters who travel by SOV, and rail users who access the stations by transit. Higher willingness to pay for the shuttle was associated with suburbanites.*

## Introduction

Traditional transit systems in the United States evolved in response to the explosion of suburban development in the first half of the 20th century. They are characterized by transit routes that resemble radial spokes of a wheel, linking residential areas in the suburbs to commercial districts in the city. Since density in these suburbs tends to be low, residents have limited access to transit stations. Most live beyond the ¼- to ½-mile walking distance of the station. The minority of commuters who do not drive to their destinations often compete for scarce park-and-ride spaces, walk, or take transit to the station. In order to encourage more residents to ride transit, it has become necessary for transit agencies to expand the services they offer to make transit more accessible. One method that transit agencies utilize is feeder shuttle service. A rail feeder shuttle in the context of this study is an innovative and demand responsive system of vehicles and information/communication technologies that provide better access to express bus or rail transit. The system is intelligent and flexible. For instance, it collects commuters from their neighborhoods and brings them to transit stations or collects them at the station to return them to their neighborhoods.

The purpose of this study is twofold. First, it evaluates the potential market penetration of rail feeder shuttle service and investigates the extent to which shuttles can expand a transit agency's service area to travelers located outside of the station's vicinity. Second, it analyzes the factors that influence riders' willingness to use, pay for, and wait for shuttles. Using the San Francisco's Bay Area Rapid Transit (BART) system as a case study, this article reports results that can be valuable to other (similar) transit agencies.

## Literature Review

A study of downtown San Francisco BART stations in the mid-1990s found that 2/3 of all access trips are by pedestrians (Cervero 1995), but as the distance between stations and the downtown increases, access to transit stations becomes increasingly limited to those with private vehicles. Automobiles account for 60 percent of access trips that are more than one mile from the nearest BART station (Cervero 1994). However, vehicle ownership does not guarantee access, due to limited parking availability. As a result, transit ridership often remains low, especially in suburban locations. For those communities that continue to opt for this type of development, the key to making transit effective is to adapt it to land-use realities. One way to increase ridership in suburban locations is to expand the service area of rail transit stations through innovative shuttle feeder systems.

Although demand responsive transit, sometimes known as dial-a-ride service, has long been a staple of paratransit systems serving the elderly and the disabled as mandated under the Americans with Disabilities Act (ADA), it is costly to implement. This is, in part, because of the need to staff a dispatch and order-taking center and, in part, because vehicles cannot be used to their highest efficiency (i.e., they make too many trips while they are empty, either to or from picking up riders). Operating cost per trip at Portland's Tri-Met is $1.99 for rail and $2.39 for bus, but more than $20.20 for demand responsive service (FY 2002). For the Chicago Transit Authority, operating expense per trip for demand response is more than $24.00 (FY 2002).

By combining smart components, such as automated dial-a-ride and scheduling and real-time vehicle location systems, vehicles can potentially carry more passengers in the same amount of time. They can also switch from operating on fixed-route schedules to flexible ones, which are more efficient during periods of low demand. With the help of new technologies, a rail feeder shuttle system could be suitable for low-demand areas and at low-demand times (i.e., off-peak hours). The system advantages also include personalization, curb-to-curb or door-to-door service, and user-orientation. Overall, such systems can improve access to line-haul, thereby increasing rail transit use more cost effectively than existing options, such as increasing parking or improving the fixed-route feeder bus system. However, a disadvantage is that such systems have not been tested and the dial-a-ride service in the context of ADA is costly.

In a survey of 40 APTS technology providers, Khattak and Hickman (1996) and Khattak, Noeimi, and Al-Deek (1998) found that innovations such as Automatic Vehicle Location (AVL) and Computer Aided Dispatch (CAD) can increase transit mode share by increasing the efficiency of transit vehicles, improving the level of service, and reducing costs. Users can benefit from reduced travel and wait times and increased security. Hickman and Blume (2001) found that by integrating shuttle service with fixed-route trips, Houston's METROLift could reduce operating costs by 15 percent and reduce travel time for 39 percent of its passengers. ADART (Autonomous Dial-a-Ride) is a completely automated system that gives trip scheduling, dispatching, and routing control to computers onboard the vehicles. The computers provide drivers with instructions to follow (Ghani and Dial 2004).

This study attempts to fill gaps in the literature by investigating willingness to use, pay for, and wait for transit feeder shuttles, assuming that innovations in rail feeder shuttles lead to costs, wait times, trip lengths, and scheduling times that are acceptable to the user. It also attempts to shed light on how transit agencies can potentially increase ridership and reduce operating subsidies by understanding demand and willingness to pay and wait for transit shuttles.

## Background

The application of demand responsive rail feeder shuttles in the Bay Area grew out of concerns that riders were leaving BART for other, largely single-occupant, modes. Given that BART is a relatively high-quality rail system serving both urban and suburban locations, the reasons were largely related to access to BART. That is, people were leaving BART partly because of constrained access, insufficient parking at several BART stations, and poor transit service to and from the stations. In addition, land-use changes were limited in the short-term.

To assess demand for the innovative rail feeder shuttle, two Northern California locales, Glen Park and Castro Valley, were selected. Smart rail shuttles are being studied as a way to create new feeder systems that collect riders over a small geographic area and carry them to the existing transit system. In the case of Glen Park, shuttles will take riders to BART in Castro Valley and will feed riders to BART and Alameda County Transit express buses. In Castro Valley, testing the automated dial-up system on a bus route run by Alameda County (AC) Transit was particularly relevant, because the bus route was a candidate for elimination due to low ridership.

## Methodology

To design the study, the Castro Valley and Glen Park neighborhoods in San Francisco were selected based on several criteria. The two study areas are similar in that they have a BART station but are relatively underserved in terms of access to the rail system, both have hilly neighborhoods with winding streets, are populated by middle- and upper-middle income households, and have similar total populations. A key difference is that Glen Park is located in an urban setting, while Castro Valley is located in a suburban setting. Homes in Glen Park are typically older row houses, while in Castro Valley they are newer and more spread out.

The locations were also selected based on sufficient variation in terms of physical city size, population density, distance from residences to existing BART stations, and racial mix. In addition, the parking supply was to be constrained at both BART stations. Additional (practical) considerations included BART interest in field testing a new shuttle service in an urban area and replacing an inefficient feeder bus service in the suburban area. The selection of these two cities made it possible to study the behavioral differences related to the shuttle service between urban and suburban neighborhoods.

## Study Design and Survey Description

We followed a cross-sectional experimental research design by (randomly) surveying an urban and a suburban location around BART stations. The expectation was that suburban residents might be more inclined to respond positively to a rail feeder shuttle compared with urban residents. Since both communities were in the San Francisco Bay Area, we were able to control experimentally for differences in macro factors such as economy and some public services. Of course, the focus on two cities in a single area limits our ability to generalize from the current study. Nonetheless, these cities can be considered as prototypical of similar cities elsewhere in the United States, and more specifically on the west coast.

After selecting the two cities, a random digit dialing survey instrument was implemented using the CATI (computer aided telephone interview) technique. A professional firm was hired for this purpose. A sample size of 800 was considered reasonable based on statistical calculations and practical (mostly budget) considerations. To increase the response rate, the contracting firm made several repeat calls to nonresponders. Respondents were required to be at least 18 years old,[1] with no more than 52 percent female and 48 percent male (the Bay Area male and female ratio).

The survey contained several hypothetical questions that asked about willingness to use, pay for, and wait for a rail feeder shuttle. The socioeconomic and travel context questions were asked in a manner typical in travel behavior surveys, which are considered fairly reliable. The hypothetical questions about willingness to use and pay for the service are based on contingent valuation studies. The question about willingness to use begins by asking:

> *Now I'd like to talk about a shuttle service that is being considered for your neighborhood to provide easy access to BART. Suppose a shuttle service was available that provided round-trip transportation to the closest BART station from a pick-up location near your home. The service would use comfortable, air-conditioned vans and pick-ups would be scheduled for convenient times throughout the day and would be coordinated with BART train schedules. Please tell me how interested you are in this type of shuttle ser-*

> *vice, without considering the cost, using a one-to-five scale where one means you are "not at all interested" and five means you are "very interested."*

The question about payment reads:

> *Suppose the per passenger cost for this BART shuttle service was $5.00 ($4.00, $3.00, $2.00, $1.00, $0.50) per one-way trip. How likely would you be to use this service? Would you say that you definitely would use this service, probably would use this service, might or might not use this service, probably would not use this service, or definitely would not use this service?*

We followed the preferred procedure for asking questions about how much a respondent was willing to pay for a product or service by first asking about a higher payment point and lowering it subsequently, if the respondent was unwilling to pay. Questions about willingness to wait were asked in a similar way:

> *I'd like you to think just about waiting times for pick-ups. How likely would you be to use this BART shuttle service if the average waiting time for pick-ups was 20 minutes (15, 10, 5 minutes)? Would you say that you definitely would use this service, probably would use this service, might or might not use this service, probably would not use this service, or definitely would not use this service?*

Responses to these questions help us address the fundamental issue: Given a high quality BART service in urban and suburban locations, how can ridership be improved by improving accessibility with innovative demand responsive transit systems? The statistical analyses provide a rigorous treatment of the collected data by estimating models of willingness to use, pay for, and wait for the service.

Given that the respondents' willingness to use, pay for, and wait for the shuttles are in response to hypothetical scenarios, our approach uses stated rather than revealed preferences. Such an approach is necessitated by the desire to assess demand before a new service (or product) is introduced. However, the approach has certain well-known drawbacks in terms of concerns about external validity and a host of behavioral reasons that potentially bias the responses (e.g., strategic, interviewer, and starting point biases). We recognize the potential for such biases in the data, despite our efforts to minimize them through survey design and statistical analysis.

## Context

Table 1 summarizes the demographics for the two study areas and provides characteristics of Castro Valley and Glen Park. Castro Valley is located 27 miles southeast of San Francisco, across the San Francisco Bay, and 13 miles south of Oakland. The Castro Valley study area has a population of 282,133 and a density of 4,543 people per square mile. Compared with results from the 2000 US Census (Summary File 3), the survey overrepresents whites and older residents. The following differences between the survey data and the census exist and are expressed as census data followed by survey data in parenthesis. The racial composition is approximately 52.8 (75.4) percent white, 10.4 (4.1) percent black, and 15.3 (11.2) percent Asian. The average age is 35.1 (49.3) years and the average household size is 2.9 (2.8) people. The road design roughly follows a grid pattern with cul-de-sacs.

### Table 1. Summary Statistics of Castro Valley and Glen Park

| **Study Area Characteristics** | Castro Valley | Glen Park |
|---|---|---|
| Population | 282,133 | 236,265 |
| Area (sq. miles) | 62.1 | 15.9 |
| Density | 4,543 | 17,744 |
| Average Housing Value | $298,300 | n/a |
| Road Design | Grid | Grid/Cul-de-Sac |

| **Demographics** | Castro Valley | | Glen Park | |
|---|---|---|---|---|
| | Survey | Census[1] | Survey | Census[1] |
| White (%) | 75.40 | 52.80 | 70.50 | 41.90 |
| Black (%) | 4.10 | 10.40 | 4.70 | 6.70 |
| Asian (%) | 11.20 | 15.30 | 12.70 | 30.70 |
| Vehicles per Household (%) | 2.50 | -- | 1.83 | -- |
| Average Age | 49.30 | 35.10 | 46.70 | 36.50 |
| Average Household Size | 2.80 | 2.85 | 2.53 | 3.03 |
| Median family income | $67,000 | -- | $68,000 | -- |
| Distance to station is ≤ 0.25 miles (%) | 20.70 | -- | 24.50 | -- |
| Distance to station is between 0.25 and 0.50 miles (%) | 6.90 | -- | 28.70 | -- |

[1] From 2000 US Census Summary File 3

Glen Park is located approximately three miles from downtown San Francisco, on the city's southern border. The population for the Glen Park survey area is 236,265 and has a density of 17,744 people per square mile. Whites, older residents, and smaller households are overrepresented. The racial distribution for the census (survey) was 41.9 (70.5) percent white, 6.7 (4.7) percent black, and 30.7 (12.7) percent Asian. The average age was 36.5 (46.7) years and the average household size was 3.03 (2.53).

The median distance a survey respondent lives from the nearest transit station is greater in Castro Valley than in Glen Park, as expected. The average respondent in Glen Park lives 7 to 8 blocks from the station, while in Castro Valley the median distance is 1 to 2 miles. Castro Valley respondents have 2.50 vehicles per household compared with 1.83 in Glen Park. Greater vehicle ownership is usually a result of higher incomes. However, the before tax income level in Glen Park is only slightly less than in Castro Valley. Even after controlling for household size, Castro Valley respondents still have 0.89 vehicles per person compared with 0.72 per person in Glen Park. This is likely a result of greater automobile dependency for Castro Valley respondents than for those in Glen Park. In Castro Valley, 81.0 percent of respondents travel solely by single-occupant vehicle (SOV) and only 10.8 percent by transit, whereas in Glen Park 57.3 travel solely by SOV and 37.8 percent use transit.

In addition, of those commuters who reported that they usually ride transit (including park-and-ride), a similar percentage of both urban (62.3 percent) and suburban (67.4 percent) commuters rode rail. The modes that commuters used to get to the rail station vary and reflect the demographics, density, and road design of the two neighborhoods. The majority of urban rail users (58.5 percent) walk or bicycle to the station, while the majority of suburban rail users (72.4 percent) access the station by SOV. Interestingly, 20.7 percent of the suburban rail users walk to the BART station.

## Descriptive Results

In the survey, respondents were asked how likely they were to use the shuttle service to get to and from the rail station if the service cost what they are willing to pay and has acceptable wait, trip-length, and scheduling times. Possible outcomes were 1 (not at all willing) to 5 (very willing), with a few respondents indicating that they were unsure. The survey indicates that there is a moderate willingness to use shuttles in both urban and suburban neighborhoods. Approximately 20 percent of respondents reported that they were "very willing" to use a shuttle, though 35 percent of respondents were "not at all willing" to use a shuttle. It should not be interpreted that 20 percent of the respondents will permanently shift from their current mode of travel to feeder shuttles. Mode choice is a long-term decision based on the perceived utility of each mode. At most, it can be expected that these respondents will use a shuttle on a trial basis, after which time they will decide if its utility is higher than that of the alternatives.

On average, suburbanites are willing to pay more for shuttle service ($1.67 vs. $1.21), even though they have more vehicles per person. Similarly, the average maximum time that an individual is willing to wait for a shuttle is greater in suburban communities (8.7 minutes vs. 7.4 minutes). This may reflect the higher cost of living for urbanites who consequently allocate less of their income to their travel budget. Additionally, this may be because suburbanites have fewer transportation options available to them and, therefore, the value they associate with additional access is greater than for urbanites. More than 40 percent of the respondents were not at all willing to pay or wait for a shuttle. Still, 10 percent were willing to pay the maximum fare level ($5) and 20 percent were willing to wait the maximum time level (20 minutes).

It is important to quantify the percentage of respondents who are willing to use the feeder shuttle by mode and their commuter status. Respondents are categorized based on their commuter status (commuter or noncommuter), mode choice, transit choice, and BART access mode. In urban areas, 21.3 percent of all respondents indicated a high willingness to try the shuttle, compared with 20.5 percent in suburban areas. Table 2 indicates the percent of respondents by mode and commuter status that are "'very willing" to use the shuttle. It shows that in urban areas, shuttles may be targeted most successfully to noncommuting SOV users (26.7 percent), noncommuting transit riders (27.6 percent), and BART users who access the station by transit (30.3 percent). In suburban areas, feeder shuttles could most successfully be targeted to noncommuting SOV users (22.1 percent), though this is not much greater than the area average. While this percent is lower than results in urban areas, targeting this relatively large group for the shuttle service can still have a substantial overall impact on the transportation system. Overall, these findings are logical, since those groups described above are either less affected by some of the negative aspects of shuttles (noncommuters), such as on-time reliability, transfers, and circuitous routing, or are accustomed to these negative aspects (BART users who access the station by transit).

It is useful to develop a profile of the groups most willing to use shuttles so that transit agencies can tailor service to meet the needs of potential customers. For example, on average, noncommuting SOV users are in their mid-60s with incomes below average. They are willing to pay, on average, slightly more than $3 per trip and to wait about 16 minutes. Transit agencies may want to consider targeting this group for safety enhancements, such as easier boarding, and should be less concerned about their price and time sensitivity. Noncommuting transit riders in urban areas are, on average, in their late 50s with incomes significantly below average. They are willing to pay an average of $1.50 per trip and wait almost 14.5 minutes. Price sensitivity is likely to be most important to this group. The average urbanite who accesses BART by transit are in their mid-30s, and have average incomes. Interestingly, they are willing to pay only $1.10 per trip and to wait only 13 minutes. This group is highly price sensitive, perhaps due to a high cost of living and a greater range of transportation options available to them. They are somewhat time-sensitive, most likely because they have fixed schedules. Transit agencies may want to focus more on providing this group with timed-transfers and direct routing. However, it should be noted that sample sizes are low and findings may not be significant.

## Model Results

This statistical analysis estimates models for three dependent variables: willingness to use (WTU); willingness to pay (WTP) for; and willingness to wait (WTW) for the rail feeder shuttle. Data were recorded for all respondents based on their willingness to use the shuttle, ranging from 1 (not at all likely) to 5 (very likely). However, only if the respondent was at least somewhat willing to use the BART shuttle were they asked about their willingness to pay and willingness to wait for it. This results in missing data due to sample selectivity, and can lead to bias because the sample is no longer random. If the error terms for both dependent variables are correlated, it is necessary to use a sample selection model. If the error terms are not correlated, a sample selection model is not necessary, and WTU can be estimated separately from WTP and WTW.

In sample selection models it is necessary to model WTU before WTP and WTW, because the decision to use a service is made before deciding how much one is

## Table 2. Respondents "Very Likely" to Try the BART Shuttle

| *Glen Park (Urban)* | *High stated willingness to try* | | *All other respondents* | | *Revealed Preferences* | |
|---|---|---|---|---|---|---|
| | *N* | *Row %* | *N* | *Row %* | *N* | *Total %* |
| Commute by SOV | 25 | 16.2 | 129 | 83.8 | 154 | 100.0 |
| Commute by carpool | 3 | 23.1 | 10 | 76.9 | 13 | 100.0 |
| Transit commuter by bus only | 4 | 33.3 | 8 | 66.7 | 12 | 100.0 |
| Transit commuter by other transit only | 1 | 12.5 | 7 | 87.5 | 8 | 100.0 |
| Transit commuter by bus or other transit | 2 | 28.6 | 5 | 71.4 | 7 | 100.0 |
| BART transit commuter accessing station by SOV (park-and-ride) | 1 | 20.0 | 4 | 80.0 | 5 | 100.0 |
| BART transit commuter accessing station by transit | 10 | 30.3 | 23 | 69.7 | 33 | 100.0 |
| BART transit commuter accessing station by walking/bicycling | 9 | 16.1 | 47 | 83.9 | 56 | 100.0 |
| Non-commuter by SOV | 20 | 26.7 | 55 | 73.3 | 75 | 100.0 |
| Non-commuter by carpool | 2 | 28.6 | 5 | 71.4 | 7 | 100.0 |
| Non-commuter by transit | 8 | 27.6 | 21 | 72.4 | 29 | 100.0 |
| Non-commuter by park and ride | 0 | 0.0 | 1 | 100.0 | 1 | 100.0 |
| Total | 85 | 21.3 | 315 | 78.8 | 400 | 100.0 |

| *Castro Valley (Suburban)* | *High stated willingness to try* | | *All other respondents* | | *Revealed Preferences* | |
|---|---|---|---|---|---|---|
| | *N* | *Row %* | *N* | *Row %* | *N* | *Total %* |
| Commute by SOV | 37 | 18.3 | 165 | 81.7 | 202 | 100.0 |
| Commute by carpool | 1 | 4.8 | 20 | 95.2 | 21 | 100.0 |
| Transit commuter by bus only | 0 | 0.0 | 2 | 100.0 | 2 | 100.0 |
| Transit commuter by other transit only | 0 | 0.0 | 2 | 100.0 | 2 | 100.0 |
| Transit commuter by bus or other transit | 0 | n/a | 0 | n/a | 0 | n/a |
| BART transit commuter accessing station by SOV (park-and-ride) | 4 | 19.0 | 17 | 81.0 | 21 | 100.0 |
| BART transit commuter accessing station by transit | 1 | 50.0 | 1 | 50.0 | 2 | 100.0 |
| BART transit commuter accessing station by walking/bicycling | 1 | 16.7 | 5 | 83.3 | 6 | 100.0 |
| Non-commuter by SOV | 27 | 22.1 | 95 | 77.9 | 122 | 100.0 |
| Non-commuter by carpool | 6 | 50.0 | 6 | 50.0 | 12 | 100.0 |
| Non-commuter by transit | 3 | 42.9 | 4 | 57.1 | 7 | 100.0 |
| Non-commuter by park and ride | 2 | 66.7 | 1 | 33.3 | 3 | 100.0 |
| Total | 82 | 20.5 | 318 | 79.5 | 400 | 100.0 |

willing to pay for it and how long to wait for it. Therefore, when WTU=1, the respondent has at least some willingness to use the shuttle, while WTU=0 indicates that the respondent has no willingness to use the shuttle. When WTU=0, WTP and WTW are missing by definition.

The binary logit WTU model differentiates between respondents who are willing to use the shuttle from those who are not. WTU is coded 1 if the respondent is at least somewhat willing to use the shuttle and 0 if they are not at all willing. WTU may also help transit agencies market shuttle services to targeted groups.

OLS regression is used to estimate willingness to pay and willingness to wait, because the variables are interval data.[2] The seven choices available for WTP were \$0, \$0.50, \$1, \$2, \$3, \$4, or \$5. The five choices available for WTW were 0, 5, 10, 15, or 20 minutes. Only those respondents who were willing to use the shuttle were asked about their willingness to pay and wait for it. WTP is an important variable because it can help transit agencies set fare rates. Since private vehicles will always be a more reliable transportation option than public transportation, WTW is important because it can indicate which groups have a greater threshold for delay and, therefore, are more likely to switch permanently to the shuttle.

In the Heckman selection model, we control for sample selectivity bias by estimating the probability of a positive willingness to use the shuttle in the binary equation (Equation 1), and then including it in the OLS model (Equation 2).

Equation 1: $z = av + u$ (binary probit)

Equation 2: $y = \beta x + \in$ (OLS)

where:

$z$ is the binary (WTU) dependent variable

$a$ are the estimated parameters

$v$ are the independent variables

$y$ is the continuous (WTP) dependent variable

$\beta$ are the estimated parameters

$x$ are the independent variables

$u$ and $\in$ are the relevant error terms

In the Heckman model, the binary probit and OLS models are estimated simultaneously.

Table 3 (pages 14-15) shows the Heckman sample selection model, along with a Heckman two-step sample selection model (which is more stable when the data are problematic) and completely separate binary and OLS models. The Heckman sample selection model has more statistically significant independent variables than the other models and provides a better fit for the data. However, since Rho (which shows correlation between u and $\in$ ) is -0.06 and -0.142 for the Heckman and Heckman two-step models, respectively, there is little correlation between the error terms, so the Heckman models are unnecessary. Results from the independent OLS and logit models, therefore, closely resemble those of the Heckman models.

The goodness of fit for the separate willingness to use and pay models estimated are reported and they are quite low (e.g., only 4% of the variation in willingness to pay is explained by the independent variables). In the logit willingness to use model, the odds ratios can be easily calculated by exp(a x).

Several variables in this analysis are notable. In line with our expectations, people who live within ½ mile of a rail station are also less willing to use the shuttle ($p<0.01$), since they are within walking distance of the station. However, while living in the urban neighborhood is negatively associated with WTU, this relationship is not statistically significant. The socioeconomic variables show that females ($p<0.05$), younger people, and elderly people are more willing to use the shuttle ($p<0.01$). In terms of current mode choice, noncommuting SOV users ($p<0.10$) and BART users accessing the station by transit ($p<0.01$) are more willing to use the shuttle than commuting SOV users, though transit users commuting by modes other than rail and bus (likely by ferry) are less willing ($p<0.10$).

For the WTP model, urbanites are less willing to pay for the shuttle than suburbanites ($p<0.01$). While this is in agreement with our hypothesis, one of the explanations we posited was that urban residents would be willing to pay less due to a higher cost of living. This variable was tested in an earlier model and was found to be insignificant. However, it still may be that urban residents are more price-sensitive because they have a wider range of transportation options available to them. Few of the race variables are significant, except that Latinos are willing to pay more for the shuttle than Caucasians. This is in agreement with our expectation that minorities are willing to pay more for the shuttle due to their transit predisposition. However, the other race variables are insignificant. BART users accessing the

## Table 3. Models of Willingness to Use and Pay for Shuttle

| | | Heckman Sample Selection | | Heckman Two-Step Sample Selection | | Independent Models | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | OLS | | Logit | |
| | Variable | Coef. | Z | Coef. | Z | Coef. | Z | Coef. | Z |
| Willingness to Pay (WTP) | Constant | 2.379 | 3.64 *** | 2.351 | 3.36 *** | 2.422 | 3.81 *** | | |
| | Urban Neighborhood | -0.363 | -2.32 ** | -0.358 | -2.21 ** | -0.370 | -2.38 ** | | |
| | Distance is<= 0.50 miles | 0.140 | 0.30 | 0.171 | 0.32 | 0.091 | 0.22 | | |
| | Income (thousands of dollars) | 0.002 | 0.17 | 0.002 | 0.18 | 0.002 | 0.16 | | |
| | Income Squared | 0.000 | -0.37 | 0.000 | -0.38 | 0.000 | -0.36 | | |
| | Black | 0.175 | 0.45 | 0.187 | 0.46 | 0.158 | 0.41 | | |
| | Asian | 0.082 | 0.35 | 0.074 | 0.30 | 0.094 | 0.40 | | |
| | Latino | 0.543 | 1.86 * | 0.537 | 1.80 * | 0.553 | 1.87 * | | |
| | Race is other | -0.477 | -1.22 | -0.489 | -1.21 | -0.460 | -1.18 | | |
| | Race is missing value | -0.191 | -0.71 | -0.207 | -0.68 | -0.167 | -0.66 | | |
| | Age | -0.004 | -0.13 | -0.001 | -0.03 | -0.008 | -0.33 | | |
| | Age Squared | 0.000 | 0.42 | 0.000 | 0.28 | 0.000 | 0.63 | | |
| | Non-commuter by SOV | 0.186 | 0.84 | 0.173 | 0.70 | 0.206 | 1.00 | | |
| | Non-commuter by transit | -0.300 | -0.84 | -0.299 | -0.84 | -0.301 | -0.83 | | |
| | Non-commute by carpool | 0.531 | 1.14 | 0.517 | 1.07 | 0.552 | 1.18 | | |
| | Commuter by bus | 0.615 | 1.16 | 0.605 | 1.13 | 0.630 | 1.18 | | |
| | Commutes by other | 0.312 | 0.32 | 0.355 | 0.34 | 0.247 | 0.26 | | |
| | Commutes by bus and other | -0.367 | -0.54 | -0.378 | -0.55 | -0.351 | -0.51 | | |
| | Travels to BART station by SOV | -0.580 | -1.37 | -0.580 | -1.37 | -0.579 | -1.34 | | |
| | Travels to BART station by transit | -0.931 | -2.31 ** | -0.961 | -1.99 * | -0.884 | -2.52 ** | | |
| | Travels to BART station by walk/bike | -0.290 | -0.75 | -0.281 | -0.71 | -0.304 | -0.78 | | |
| | Rho | -0.086 | | -0.142 | | | | | |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Willingness to Use (WTU) Yes=1, No=0 | Constant | 2.369 | 5.33 | *** | 2.369 | 5.33 | *** | | | | 3.877 | 5.12 | *** |
| | Urban Neighborhood | -0.124 | -1.21 | | -0.126 | -1.24 | | | | | -0.205 | -1.22 | |
| | Distance is<= 0.50 miles | -0.706 | -2.59 | *** | -0.712 | -2.62 | *** | | | | -1.207 | -2.69 | *** |
| | Black | -0.185 | -0.78 | | -0.182 | -0.77 | | | | | -0.286 | -0.74 | |
| | Asian | 0.200 | 1.21 | | 0.202 | 1.22 | | | | | 0.339 | 1.22 | |
| | Latino | 0.162 | 0.81 | | 0.163 | 0.81 | | | | | 0.249 | 0.75 | |
| | Race is other | 0.259 | 0.91 | | 0.258 | 0.91 | | | | | 0.408 | 0.86 | |
| | Race is missing value | 0.381 | 2.17 | ** | 0.382 | 2.18 | ** | | | | 0.681 | 2.27 | ** |
| | Male | -0.271 | -2.81 | *** | -0.268 | -2.80 | *** | | | | -0.451 | -2.84 | *** |
| | Age | -0.070 | -4.01 | *** | -0.070 | -4.00 | *** | | | | -0.115 | -3.87 | *** |
| | Age Squared | 0.001 | 3.37 | *** | 0.001 | 3.37 | *** | | | | 0.001 | 3.27 | *** |
| | Non-commuter by SOV | 0.252 | 1.82 | * | 0.253 | 1.83 | * | | | | 0.428 | 1.85 | * |
| | Non-commuter by transit | 0.032 | 0.14 | | 0.034 | 0.15 | | | | | 0.066 | 0.18 | |
| | Non-commute by carpool | 0.187 | 0.56 | | 0.188 | 0.57 | | | | | 0.321 | 0.57 | |
| | Commuter by bus | 0.160 | 0.42 | | 0.156 | 0.41 | | | | | 0.229 | 0.37 | |
| | Commutes by other | -0.848 | -1.90 | * | -0.847 | -1.89 | * | | | | -1.336 | -1.85 | * |
| | Commutes by bus and other | 0.444 | 0.71 | | 0.426 | 0.69 | | | | | 0.774 | 0.68 | |
| | Travels to BART station by SOV | -0.020 | -0.07 | | -0.019 | -0.07 | | | | | -0.012 | -0.03 | |
| | Travels to BART station by transit | 0.735 | 2.63 | *** | 0.743 | 2.67 | *** | | | | 1.312 | 2.61 | *** |
| | Travels to BART station by walk/bike | -0.048 | -0.18 | | -0.043 | -0.16 | | | | | -0.044 | -0.10 | |
| Summary Statistics | Number of obs | 800 | | | 800 | | | 517 | | | 800 | | |
| | F Stat/P>Chi2 | 0.85 | | | | | | 2.21 | | | | | |
| | Goodness of fit | | | | | | | 0.04 | | | 0.07 | | |
| | Log Likelihood | -1452.7 | | | | | | | | | -482.7 | | |

*** Significant at the 99% confidence level
** Significant at the 95% confidence level
* Significant at the 90% confidence level

## Table 4. Models of Willingness to Use and Wait for Shuttle

| | | Heckman Sample Selection | | Heckman Two-Step Sample Selection | | Independent Models | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | OLS | | Logit | |
| | Variable | Coef. | Z | Coef. | Z | Coef. | Z | Coef. | Z |
| Willingness to Wait (WTW) | Constant | 12.702 | 4.82 *** | 14.931 | 3.13 *** | 12.319 | 4.87 *** | | |
| | Urban Neighborhood | -1.037 | -1.66 * | -1.418 | -1.49 | -0.972 | -1.57 | | |
| | Distance is<= 0.50 miles | -2.226 | -1.20 | -4.511 | -1.05 | -1.837 | -1.11 | | |
| | Income (thousands of dollars) | -0.059 | -1.22 | -0.059 | -1.22 | -0.059 | -1.19 | | |
| | Income Squared | 0.000 | 0.23 | 0.000 | 0.23 | 0.000 | 0.22 | | |
| | Black | 2.794 | 1.82 * | 2.169 | 1.07 | 2.903 | 1.88 * | | |
| | Asian | 1.181 | 1.26 | 1.728 | 1.21 | 1.086 | 1.17 | | |
| | Latino | 3.074 | 2.64 *** | 3.560 | 2.27 ** | 2.990 | 2.56 ** | | |
| | Race is other | -2.637 | -1.71 * | -1.856 | -0.83 | -2.769 | -1.79 * | | |
| | Race is missing value | -1.536 | -1.40 | -0.346 | -0.15 | -1.743 | -1.74 * | | |
| | Male | 1.311 | 1.99 ** | 0.502 | 0.33 | 1.450 | 2.47 ** | | |
| | Age | 0.036 | 0.28 | -0.165 | -0.46 | 0.071 | 0.71 | | |
| | Age Squared | 0.000 | -0.06 | 0.002 | 0.53 | 0.000 | -0.36 | | |
| | Non-commuter by SOV | 2.059 | 2.39 ** | 2.813 | 1.77 * | 1.927 | 2.35 ** | | |
| | Non-commuter by transit | 2.575 | 1.82 * | 2.599 | 1.60 | 2.574 | 1.79 * | | |
| | Non-commute by carpool | 1.831 | 0.99 | 2.387 | 1.01 | 1.734 | 0.93 | | |
| | Commuter by bus | 3.881 | 1.85 * | 4.380 | 1.68 * | 3.794 | 1.79 * | | |
| | Commutes by other | -5.704 | -1.47 | -8.655 | -1.37 | -5.198 | -1.38 | | |
| | Commutes by bus and other | 0.943 | 0.35 | 1.873 | 0.51 | 0.780 | 0.29 | | |
| | Travels to BART station by SOV | 0.058 | 0.03 | -0.016 | -0.01 | 0.072 | 0.04 | | |
| | Travels to BART station by transit | -0.343 | -0.22 | 1.704 | 0.44 | -0.691 | -0.50 | | |
| | Travels to BART station by walk/bike | -0.670 | -0.43 | -1.040 | -0.55 | -0.602 | -0.39 | | |
| | Rho | 0.165 | | 0.879 | | | | | |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Willingness to Use (WTU) Yes=1, No=0 | Constant | 2.374 | 5.33 | *** | 2.369 | 5.33 | *** | | 3.877 | 5.12 | *** |
| | Urban Neighborhood | -0.128 | -1.25 | | -0.126 | -1.24 | | | -0.205 | -1.22 | |
| | Distance is<= 0.50 miles | -0.730 | -2.65 | *** | -0.712 | -2.62 | *** | | -1.207 | -2.69 | *** |
| | Black | -0.180 | -0.76 | | -0.182 | -0.77 | | | -0.286 | -0.74 | |
| | Asian | 0.200 | 1.21 | | 0.202 | 1.22 | | | 0.339 | 1.22 | |
| | Latino | 0.161 | 0.80 | | 0.163 | 0.81 | | | 0.249 | 0.75 | |
| | Race is other | 0.267 | 0.94 | | 0.258 | 0.91 | | | 0.408 | 0.86 | |
| | Race is missing value | 0.380 | 2.17 | ** | 0.382 | 2.18 | ** | | 0.681 | 2.27 | ** |
| | Male | -0.270 | -2.81 | *** | -0.268 | -2.80 | *** | | -0.451 | -2.84 | *** |
| | Age | -0.070 | -4.01 | *** | -0.070 | -4.00 | *** | | -0.115 | -3.87 | *** |
| | Age Squared | 0.001 | 3.38 | *** | 0.001 | 3.37 | *** | | 0.001 | 3.27 | *** |
| | Non-commuter by SOV | 0.249 | 1.80 | * | 0.253 | 1.83 | * | | 0.428 | 1.85 | * |
| | Non-commuter by transit | 0.041 | 0.18 | | 0.034 | 0.15 | | | 0.066 | 0.18 | |
| | Non-commute by carpool | 0.190 | 0.57 | | 0.188 | 0.57 | | | 0.321 | 0.57 | |
| | Commuter by bus | 0.152 | 0.40 | | 0.156 | 0.41 | | | 0.229 | 0.37 | |
| | Commutes by other | -0.848 | -1.90 | * | -0.847 | -1.89 | * | | -1.336 | -1.85 | * |
| | Commutes by bus and other | 0.410 | 0.67 | | 0.426 | 0.69 | | | 0.774 | 0.68 | |
| | Travels to BART station by SOV | -0.017 | -0.06 | | -0.019 | -0.07 | | | -0.012 | -0.03 | |
| | Travels to BART station by transit | 0.763 | 2.70 | *** | 0.743 | 2.67 | *** | | 1.312 | 2.61 | *** |
| | Travels to BART station by walk/bike | -0.028 | -0.10 | | -0.043 | -0.16 | | | -0.044 | -0.10 | |
| Summary Statistics | Number of obs | 800 | | | 800 | | | 517 | 800 | | |
| | F Stat/P>Chi2 | 0.73 | | | | | | 4.25 | | | |
| | Goodness of fit | | | | | | | 0.12 | 0.07 | | |
| | Log Likelihood | -2163.4 | | | | | | | -482.7 | | |

*** Significant at the 99% confidence level
** Significant at the 95% confidence level
* Significant at the 90% confidence level

station by transit are less willing to pay for the feeder shuttle than commuting SOV users ($p<0.05$).

Table 4 shows models for WTU and WTW. Results for WTU are nearly identical to those found in Table 3, as expected. For WTW, the Heckman sample selection model again has a low correlation between error terms (Rho=0.165) and is, therefore, not necessary. The results from the OLS model are similar to those of the Heckman model. Both Blacks ($p<0.10$) and Latinos ($p<0.05$) are willing to wait longer for the shuttle than Caucasians. This is likely due to their transit disposition. In addition, females are willing to wait about 1.5 minutes less than males ($p<0.10$), likely due to safety concerns. In terms of current mode choice, noncommuting SOV users ($p<0.05$), noncommuting transit users ($p<0.10$), and bus commuters ($p<0.10$) are willing to wait longer for the shuttle, by approximately 2, 2½, and 4 minutes, respectively.

While travel time to the nearest transit station is an important measure of impedance, it was not included in the final model due to missing data in the variable and statistical insignificance in previous models.

## Conclusions

The purpose of this research was to investigate whether transit agencies can use rail feeder shuttles to expand their service to underserved areas and those groups who will use the service. Using a behavioral survey in two San Francisco neighborhoods, this study attempted to answer this question in two ways. First, it sought to profile those groups who are most likely to switch to the proposed shuttle service. The study shows that there is significant interest in using rail feeder shuttles, as long as they have acceptable fares, wait times, trip lengths, and scheduling times. As is to be expected, there is no one-size-fits-all approach to offering feeder shuttle service. Rather, service must be tailored to individual groups to meet their needs. This survey found that three mode choice groups, in particular, show promise as target groups: noncommuting SOV users, noncommuting transit users in urban areas, and rail users who access stations by transit in urban areas. In terms of socioeconomics, women, younger, and elderly people also show promise. The challenge for transit agencies is to provide passengers with the level of service that they require. By funding advanced technologies, transit agencies can improve level of service for passengers while reducing costs to service providers by improving scheduling, routing, transfers, and passenger information.

Second, the research rigorously analyzed the factors that influence willingness to use, pay, and wait for rail feeder shuttles. Higher willingness to use the shuttle was associated with living beyond the ½-mile walking distance of the nearest transit station, women, younger, and elderly respondents, noncommuters who travel by SOV, and BART users who access rail stations by transit. Higher willingness to pay for the shuttle was associated with suburbanites and Latinos, although BART users accessing the station by transit are less willing to pay for the shuttle. Higher willingness to wait for a shuttle was associated with Blacks, Latinos, males, as well as noncommuting SOV users, noncommuting transit riders, and bus commuters. Overall, the study finds that a consumer-based shuttle service might be feasible, especially if targeted at those groups most willing to use the shuttle. Transit agencies may be able to more accurately price the shuttle service fare and develop scheduling policies based on the results of this study. Policymakers can consider rail feeder shuttles as a valuable alternative in bringing demand from lower density areas to increase the accessibility of line-haul services.

There are certain limitations. First, the CATI survey was intended to satisfy sample requirements for gender and age (above 18). However, as we point out in discussing the context, the survey responses show overrepresentation of certain groups (whites and older residents) compared with the 2000 census data. This might limit the generalization of the findings. Second, compared to other cities, San Francisco is somewhat unique in terms of population, openness to innovations, and geography. Issues investigated in this study are context-specific and may not generalize to other cities. Still, this study clearly suggests that public transportation planners in other (similar) large metropolitan areas should explore and evaluate expanding transit service to underserved urban and suburban areas via shuttles.

Shuttle trips would be part of a linked trip (shuttle and line-haul). Therefore, shuttle choice should be nested within a larger choice set. This would require people to weigh door-to-door travel times, not just time (or distance) for the shuttle link. Future research on shuttles should investigate them as part of a linked trip.

## Endnotes

[1] Minors are also potential transit shuttle passengers, however they are excluded due to privacy concerns.

[2] Since the data are categorical, rather than interval, there is potential for violation of OLS assumptions.

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# Using GPS Technology to Measure On-Time Running of Scheduled Bus Services

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## Abstract

*Assessing bus service running times has been a difficult and expensive task for many urban bus operators. This has restricted the ability of operators to collect adequate data to identify problems and improve service levels. Passive Global Positioning System (GPS) devices offer a low-cost means of collecting large amounts of highly accurate data, to be used in an ongoing performance assessment program. Some programming skills are required to break continuous GPS data into information that is meaningful to a scheduler. This article provides an overview of a software application developed to process and analyze GPS datasets collected by a bus operator in Sydney, Australia, in 2002-2003. The data collection procedure and processing algorithms are described, and examples are presented of output produced by the software. The algorithm developed to process the GPS data worked well. We conclude that passive GPS is a cost-effective method of collecting data on performance. For operators running buses on five or more routes, system development costs could be recovered within two to three years.*

## Introduction

This article provides an overview of a pilot Global Positioning System (GPS) research project undertaken in late 2002/early 2003 by the Institute of Transport Studies at the University of Sydney and a bus operator in Sydney, Australia. The aim of the project was to develop a cost-effective Geographic Information System (GIS) based program to process and analyze GPS data collected on buses operating on a specific route.

The article presents an overview of the steps taken to collect the input data used in the project, and details the trip-processing and timetable query program developed for processing and analyzing the GPS data. Some examples are presented of output produced by the main trip-processing and timetable query program, as well as some of the ways it can be used by schedulers. It is concluded that for operators of most sizes, passive GPS is an attractive method of collecting data on performance.

## Background: Difficulties of Measuring On-Time Running

Assessing running times of bus services has traditionally been a difficult and expensive task for the majority of bus operators in Australia and in other parts of the world (Kharola, Gopalkrishna, and Prakash 2003). Until recently, travel times have generally been collected manually by timekeepers positioned at key points along a given route or service corridor. The time-consuming nature of this process restricts the ability of operators to collect large and meaningful samples of data, which could be used to improve timetables and levels of service. It is also difficult, if not impossible, to identify congestion points from such data, and to evaluate the impact that they might have on overall service levels.

Automatic vehicle location (AVL) technology offers a means of collecting large samples of travel time data, which can be used as part of an ongoing performance assessment program. The rapid pace of change in AVL systems, however, can make investment decisions difficult for many bus operators. In the past few years, a number of sophisticated on-line systems have been developed for providing information to customers about bus arrival times, allocating priority at traffic lights, and enabling bus operators to respond to traffic problems in real time (GPS Online 2000; Morehead 2001; Infodev 2003; NextBus 2003). Such applications are not cheap to develop, and may cost in the vicinity of hundreds of thousands, or even millions of dollars. In Auckland, New Zealand, a large-scale real-time passenger information (RTPI)/bus priority system is being developed that will involve fitting more than 700 buses with GPS equipment, providing on-street variable passenger information displays, and modifying traffic lights. The estimated cost of this project is NZD $7 million (Auckland City Council 2003). The system developed for the London bus network is probably one of the largest AVL systems set up to date. There are currently more than 8,000 buses using the system, and passenger information screens will be fitted to 4,000 stops by the time the rollout is complete. To date, almost GBP $50 million has been spent developing the system (GIS Development 2004). AVL systems are also being integrated with automatic passenger count (APC) systems to provide information on boardings and alightings and passenger kilometres of travel (Rossetti and Turitto 2000).

Although relatively little work has been done to evaluate the benefits of these systems, there is evidence to suggest they can have a positive impact on operational efficiency. Strathman et al. (2000) examined a computer aided dispatching and AVL system developed in Portland, Oregon, and found that the system improved on-time performance and reduced total running times. While real-time systems indubitably have a range of benefits, much less is known about the effects they ultimately have on patronage (which is why they are developed in the first place).

The high costs of integrated AVL systems require them to be largely funded by transport authorities, as opposed to individual operators. This is especially the case when systems involve modifications to state-owned assets such as bus stops and roads. Passive or off-line GPS technology, operating independently of other systems, represents a practical, low-cost method for collecting travel time data. Over the past few years, GPS technology has improved markedly and accurate GPS data loggers have become very affordable, and can be purchased for as little as USD $200 to $300. The appeal of this technology lies in its simplicity and affordability. In many situations, operators may only require information to help determine whether their buses are running on time, and where problems might be occurring on the network. Such information does not need to be available in real time to be useful.

One of the key advantages in using data loggers is that they are portable, and can be moved easily between buses operating on different routes and in different regions. Other than a major study undertaken by Kharola et al. (2003) in Bangalore, India, it appears that little work has been done to date using off-line systems to collect GPS data on buses.

Despite the advantages of passive GPS, there are some practical difficulties that need to be overcome when using portable data loggers. These difficulties stem from the fact that low-cost data loggers collect GPS data independently of other systems within the bus, such as on-board ticketing systems. Output files from passive data loggers provide continuous streams of spatial and temporal data (i.e., geographic coordinates, time and date), but no other meaningful reference information (e.g., the route the bus was operating on, trip start and end times, shift changes).

While it would seem practical to use a GPS device that would allow drivers to enter additional reference information, this would probably just make the system unreliable. Bus drivers work in a relatively stressful environment and it is likely that they would often forget to indicate when they started and finished routes or arrived and departed from the depot. Likewise, fully automatic or integrated systems may not be an option because of expenses involved in modifying or upgrading ticketing systems.

Some programming skills are required to convert continuous points into records that are more useful to an operator. Several important tasks need to be undertaken before analysis can take place. First, periods of in-service or out-of-service running need to be defined, and routes need to be identified. This can be a complicated task because operators often design shifts so that buses may switch between different areas and routes, from trip to trip, to maximize vehicle utilization. Once routes are identified, individual trips must then be matched with a timetable to compare scheduled and actual running times.

## Input Data

Three main sources of data were required to develop the programs: bus stop coordinates, timetable information, and in-vehicle GPS data collected from the study route. The following sections describe the methods used to collect and edit the input data. All GPS data used in this project were collected using GeoLogger® passive nondifferential GPS data loggers, produced by GeoStats. The Geologgers were fitted with Garmin GPS receivers which have an accuracy rating of ±15 meters, although the experience of the Institute of Transport Studies is that on average it is closer to ±5 meters. All GIS programs were developed using the GISDK™ programming language in Caliper Corporation's TransCAD® package.

### *Bus Stop Data*

Although a database of bus stop locations is held by the NSW State Government, these data were not considered to be sufficiently accurate for this project. Bus stop coordinates were, therefore, collected by the bus operator in late November 2002, using a data logger and a company vehicle. Arrival times at major timing points along the route were recorded, and the GPS data were downloaded and put into separate layers for inbound and outbound stops.

### *Timetable Data*

Timetable data were generated from the scheduling software used by the bus operator and saved in Excel spreadsheets. Minor modifications were required to convert the data into a format that could be recognized by the GIS program. Numerical values stored as times were converted to integers, and columns and rows were transposed, so that each row of the table represented a trip, with columns representing the scheduled arrival times at timing points along the route.

### *In-Vehicle Bus Data*

Data were collected from four buses, starting in late December 2002 and finishing in mid-March 2003. Four buses operating principally on the study route were fitted with data loggers. A formal sampling plan was not considered necessary because the project was mainly focused on development of methodology, and because only one route was considered.

Because the devices were designed to be plugged into the cigarette lighter outlet of an ordinary motor vehicle, some modifications were needed so that the power cords could be plugged into the AV accessory outlets of the buses. Other than this, the devices were relatively easy to install. GPS antennas were easily attached to the roofs of the buses because of their magnetic bases. It was not known what polling rate would be most suitable, so two of the devices were set to record data on one-second intervals, while the other data loggers were set on five seconds. Data were collected 24 hours a day during the study period because the accessory outlets in the buses were constantly powered. As a result, the data loggers needed to be downloaded and cleared every few days.

## Trip-Processing Algorithm and Timetable Query

The trip-processing algorithm and timetable query was the core program designed to generate travel time output from the GPS data files. There are essentially three main tasks performed by the algorithm within the program. First, continuous GPS records are broken into separate blocks of records, or basic trips (trip definition). Next, the program examines these basic trips, determines the type of trip made, and analyzes running times and travel times between timing points. In the third part of the program, GIS maps, layers, and selection sets are created so that processed data can be viewed and analyzed by the user.

### *Trip Definition*

Three criteria were used to break continuous data into basic trips. In deciding where to insert a break point or trip end, the program examines:

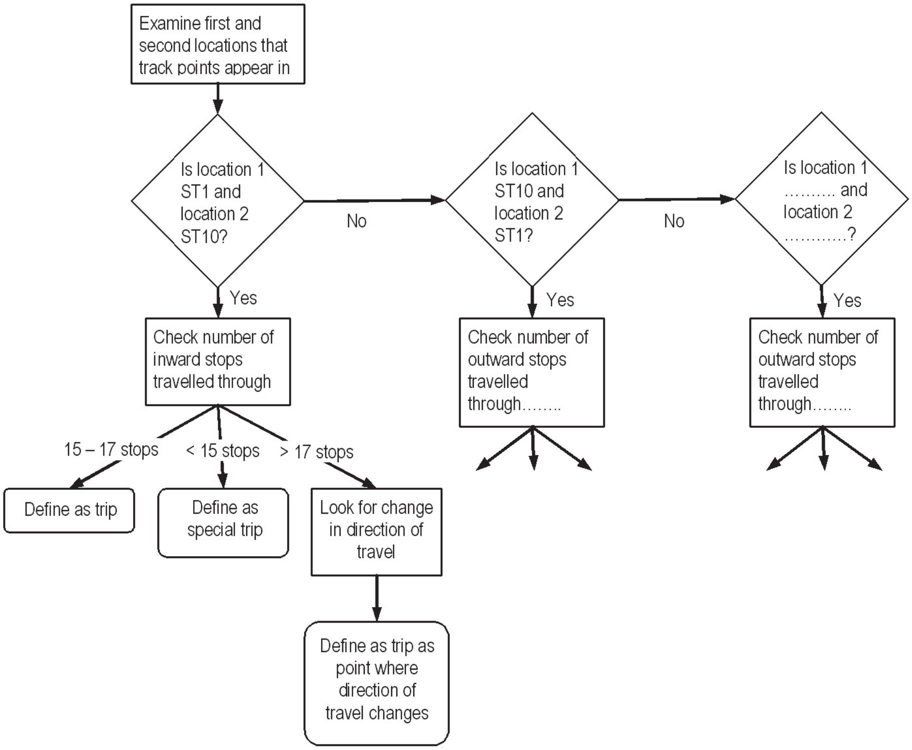
1. Whether records appear in one of three areas: the depot (Depot), and the two end points of the route (stop 1 and stop 17)
2. The number of bus stops traveled through on the study route
3. Any reversal in the direction of travel

In the first step taken in the trip definition process, coordinates of the depot and bus stops are loaded into a temporary array. The location of each GPS record is examined and an additional array is created identifying GPS records that are located within 50 meters of a bus stop, and 120 meters of the depot. When more than one point is located within the radius, the identification of the closest point to the center is recorded in the array. GPS records are then sorted into separate groups within the GIS layer (selection set) for each day.

For each day's worth of records, the program searches for points that start or end at the depot, stop 1 (ST1), or stop 17 (ST17). That is, if the first record of the day is found within the depot, the program then looks for the next location that subsequent records appear in. There are three possible locations considered—the depot, ST1, or ST17 (if more routes were defined within the program structure, more end points would be searched). If a bus drove from the depot in the morning to one end of the route, stopped briefly to pick up passengers and then made a scheduled trip along the study route, the depot would be the first location marked, ST1 the second, and ST17 the third.

Within each combination of the three locations (depot–ST1, depot–ST17, ST1–ST17, etc.), a separate series of subcommands examines the number of stops passed to determine the likely trip ends. Figure 1 provides an illustration of how this process works. If a bus traveled from ST1 to ST10 and passed through 15 to 17 stops, this would mean that the bus traveled along the study route without deviation, and the trip end would therefore be defined as ST17. If the number of stops was less than 15, this would mean the bus traveled only part of the route and so the trip would be coded as a "special trip" (e.g., if a bus ran back to the depot via some alternative route to save time). If the number of stops is greater than 17, then it was likely that the bus has made more than one trip, and the trip end would be defined as the point that the bus changed its direction of travel (a change from inbound to outbound). A similar sequence of commands is used to examine records between the three main locations.

**Figure 1. Process Used to Define Basic Trips**



## *Trip Type Definition and Timetable Query*

Once the program has flagged the likely start and end points of trips, the algorithm then defines the type of trip made. Beginning with the first trip of the first day, the program examines each set of records and classifies them into one of the following categories: Route A (main study route), route B, route C, trips out from the depot (O_Depot), trips into the depot (I_Depot), trips made out from the depot and straight back to the depot without stopping (D_2_D) and unknown trips (UNKNOWN). The direction (inbound or outbound) is also determined for each route.

Whenever the program detects a trip made along the study route, a subroutine assesses on-time running and measures the time taken to travel between timing points. On-time running is measured by comparing the time the bus arrived at a timing point (the time recorded by the data logger) with the time that the bus was scheduled to arrive (the time shown on the timetable). This requires each GPS trip made along the study route to be correctly matched with trips shown on the timetable. From the data observed as part of the validation procedure, it was noted that most buses tend to start within just a few minutes of their scheduled start time; thus, in most cases, it appeared quite easy to determine which GPS trip belonged to which timetable trip.

Once the GPS and timetable start times have been matched, the program then examines the time the bus arrived at each timing point, and calculates the difference between the GPS arrival time, and the scheduled arrival time. Travel times are also calculated between each set of timing points.

### *Creation of Maps and Output Files*

The program opens a base map stored in the specified directory and imports the GPS data in the form of a single GIS point layer. Within this layer, each trip is marked within a selection set. A number of different output files are produced, including a trip summary file and timing check output files for both inward and outward directions. Table 1 shows a selection of data contained in the trip summary output file. Start and end times are shown for each trip as well as the time that the bus was stationary between trips (lay-up time). Scheduled travel times are shown for trips that were made along the study route (Route A).

Table 2 shows a sample of output generated from the timetable query. The columns with single timing point names (ST1, ST2, etc.) show the difference between the scheduled arrival time, and the actual GPS arrival time for each of the timing points along the study route. Columns with multiple timing points (ST1_ST2, ST2_ST3 etc.) show travel times recorded by the GPS between timing points.

GIS is a very powerful tool for visualizing spatial data; however, the data query features in most standard GIS packages are relatively simple and do not allow users to specify multiple attributes or conditions within a single query. A data selection set toolbox was designed as a visualization tool to allow people not overly familiar

## Table 1. GPS Data Summary File

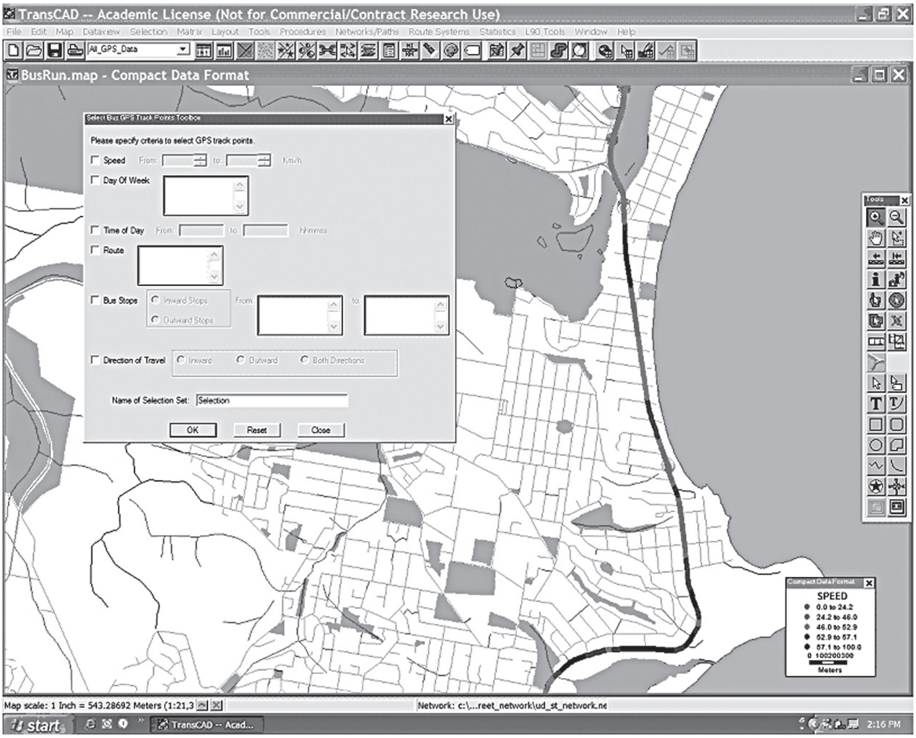
| Date | Route | Dir. | Start Time | End Time | Layup Time | Travel Time | Scheduled Travel Time |
|---|---|---|---|---|---|---|---|
| 161202 | O_Depot | Out | 6:39:58 | 6:54:23 | | 00:14:25 | |
| 161202 | Route C | In | 6:54:32 | 8:16:23 | 0:00:09 | 01:21:51 | |
| 161202 | Route C | Out | 8:40:13 | 10:05:36 | 00:23:50 | 01:25:23 | |
| 161202 | I_Depot | In | 10:06:11 | 10:15:16 | 0:00:35 | 0:09:05 | |
| 161202 | O_Depot | In | 16:26:29 | 17:18:11 | 06:11:13 | 00:51:42 | |
| 161202 | UNKNOWN | Out | 17:19:06 | 18:33:47 | | 01:14:41 | |
| 161202 | I_Depot | In | 18:34:28 | 18:43:08 | 0:00:41 | 0:08:40 | |
| 171202 | O_Depot | Out | 5:12:08 | 5:22:08 | 10:29:00 | 00:10:00 | |
| 171202 | Route A | In | 5:22:13 | 6:33:19 | 0:00:05 | 01:11:06 | 01:18:00 |
| 171202 | Route A | Out | 6:57:29 | 8:30:35 | 00:24:10 | 01:33:06 | 01:43:00 |
| 171202 | Route A | In | 8:59:56 | 10:50:58 | 00:29:21 | 01:51:02 | 01:38:00 |
| 171202 | Route A | Out | 11:00:23 | 12:45:10 | 0:09:25 | 01:44:47 | 01:43:00 |
| 171202 | Route A | In | 13:02:11 | 14:45:53 | | 01:43:42 | 01:38:00 |
| 171202 | Route A | Out | 14:54:38 | 16:38:55 | 0:08:45 | 01:44:17 | 01:43:00 |
| 171202 | Route A | In | 17:02:55 | 18:43:56 | 00:24:00 | 01:41:01 | 01:38:00 |
| 171202 | Route A | Out | 18:57:21 | 20:30:57 | 00:13:25 | 01:33:36 | 01:33:00 |
| 171202 | I_Depot | In | 20:35:12 | 20:53:37 | 0:04:15 | 00:18:25 | |

## Table 2. GPS Travel Time Output File

| TRP_ ID_S | ROUTE_ NO | DATE | WEEK DAY | TT_ DAY | S_TIME | S_TIME _S | ST1 | ST1 ST2 | ST2 | ST2_ ST3 |
|---|---|---|---|---|---|---|---|---|---|---|
| 5 | Route A | 281202 | Saturday | 2 | 6:33:46 | 6:30:00 | 3:46 | 7:24 | 1:10 | 3:06 |
| 9 | Route A | 281202 | Saturday | 2 | 12:51:28 | 12:50:00 | 1:28 | 10:09 | :37 | 3:46 |
| 11 | Route A | 281202 | Saturday | 2 | 16:51:58 | 16:50:00 | 1:58 | 14:30 | 5:28 | 5:00 |
| 13 | Route A | 281202 | Saturday | 2 | 20:52:22 | 20:47:00 | 5:22 | 6:15 | 3:37 | 2:05 |
| 20 | Route A | 291202 | Sunday | 3 | 9:51:12 | 9:50:00 | 1:11 | 8:42 | -1:07 | 5:00 |
| 23 | Route A | 291202 | Sunday | 3 | 16:02:30 | 15:50:00 | 12:30 | 14:25 | 15:55 | 4:21 |

with GIS to run advanced queries on a large dataset. Figure 2 shows the selection set toolbox in TransCAD®. The toolbox allows GPS records to be filtered using any combination of the following six criteria: speed, day of week, time of day, route, timing points, and direction of travel. Once selected, the user can apply color themes on average speeds to highlight points of congestion along the route.

Figure 2. GIS Query Tool



Please specify criteria to select GPS track points.

☐ Speed From: to: Km/h
☐ Day Of Week
☐ Time of Day From: to: hhmmss
☐ Route
☐ Bus Stops ○ Inward Stops ○ Outward Stops From: to:
☐ Direction of Travel ○ Inward ○ Outward ○ Both Directions

Name of Selection Set: Selection

OK Reset Close

### *Validation*

The programs were validated using eight GPS data files collected from December 2002 to March 2003. Two files were selected from each of the four buses that collected data, to ensure an even spread of dates and a balance between the various polling rates. GPS summary files and timing check files were compared with fare collection data reports provided by the bus operator. These reports were generated from data downloaded from driver smart cards, and represent a record of actual schedules (as opposed to planned schedules developed in the scheduling software). Although there are a number of limitations of using fare collection data (shift times are shown but not bus operation times, in-depot and out-depot movements are not specifically identified), they provide a reasonable record with which to compare the GPS data. Two main tasks were performed as part of the validation process. First, summary files were checked to ensure that trip types (i.e., the route) were correctly defined. Second, timing check files were examined to make sure that GPS trips were correctly matched with the timetable.

Overall, the trip detection algorithm worked well. Table 3 shows a breakdown of trips detected by the trip-processing algorithm for the eight data files. Of the 251 trips detected, 96 were Route A trips. Route B and Route C trips comprised 11 percent of the trips detected by the program, while around 100 trips were made to and from the depot. Three trips were made where the bus left the depot, drove two or three blocks, and then drove straight back to the depot.

## Table 3. Trips Detected by Trip-Processing Algorithm

| Trip Destinations | No. of Trips | Trips as % of Total | No. of Undetected/ Misclassified Trips | Undetected/ Misclassified Trips as % within Group |
|---|---|---|---|---|
| Route A | 96 | 38.2% | 0 | 0.0% |
| Route B | 2 | 0.8% | 0 | 0.0% |
| Route C | 25 | 10.0% | 0 | 0.0% |
| In Depot | 50 | 19.9% | 7 | 12.0% |
| Out Depot | 51 | 20.3% | 5 | 9.8% |
| Depot - Depot | 3 | 1.2% | 0 | 0.0% |
| Unknown | 24 | 9.6% | 24 | 100.0% |
| Total Trips | 251 | 100.0% | 35 | 13.9% |

No errors or inconsistencies were found in any of the 123 trips coded as Route A, B, or C, which suggests the program interpreted the data very well. Table 3 also shows the number of trips that went undetected or were misclassified by the program. A total of 12 trips were misclassified as either in-depot or out-depot. Of the 7 trips within the in-depot group, 4 were actually Route A trips which appeared to end prematurely. The remaining 3 trips, misclassified as in-depot, incorporated travel made on routes not defined within the program structure and could not be correctly interpreted. Five out-depot trips also incorporated travel on a number of routes which were not defined within the program structure.

A total of 24 trips went undetected by the program and were coded as unknown. Table 4 provides an explanation of what actually took place in the case of each of these trips. Eight of the trips were Route A trips which were missed for a variety of reasons. Seven of these 8 trips were missed because of signal loss, principally around the final stop that the bus traveled to in the CBD (ST17). Interestingly, 5 of these events (and one third of the total unknown trips) occurred in one data file, which suggests there may have been some power problems with the memory storage unit. (When the battery of a memory storage unit becomes low, data often become patchy.) Four Route C trips were also missed because of signal problems. A total of 10 trips were coded as unknown because the routes were not defined within the program structure. Two other trips were missed because of a data logger malfunction (duplicate time values), the cause of which was probably low power or a bad signal.

## Table 4. Explanation of Unknown Trips

| Trip Description | No. of Occurrences |
|---|---|
| Route A, with loss of signal | 8 |
| Route B and C, with loss of signal | 4 |
| Undetectable routes | 10 |
| Other Data logger fault | 2 |
| Total | 24 |

Urban canyon effects degraded the quality of CBD-based travel time output and, unfortunately, these problems could not be fully resolved. Travel times between CBD stops were often coded as missing in output files because no points would be recorded within the buffer areas, despite the fact the bus would have passed the stops. Because the study routes ended just outside the city, urban canyon problems generally caused no problems in the trip definition component of the program. If the route finished in some other part of the city, urban canyon effects would have caused significant problems because in many cases, track points may not have appeared in the first or last stops. This would have resulted in a lot more trips being coded as unknown.

The algorithm developed to compare GPS times with the timetable also worked well. Start times appeared to be correctly matched against all 96 trips made along the study route. In almost all cases, it was fairly obvious that the correct time was selected by the program because the GPS start time was no more than a few minutes before or after the scheduled start time (headway was 30 minutes for most times of the day).

No evidence was found to suggest that a one-second polling rate was superior to a five-second rate. There was no observable difference in travel time output produced from one- and five-second files and a one-second polling rate appears to offer no benefits to offset its greater memory storage requirements. If the data loggers used for this project were set to five seconds and only recorded while the bus was in motion, the memory storage units could probably have been left in the buses for around two or three weeks before they needed to be changed.

## Assessing On-Time Running

A specialized Excel spreadsheet was developed to allow users to manipulate output files produced by the programs developed in TransCAD®, and to generate statistics on travel times and differences between scheduled times and actual running times. According to Strathman et al. (2000), these are probably the most widely recognized indicators of service reliability. The spreadsheet was designed to allow GPS data to be filtered according to date, day of week, time of day, route, bus number, and travel times.

Table 5 shows a summary of the output data generated by the timetable query. Differences are shown between GPS travel times and scheduled travel times for all inbound trips made along the study route in the validation files. These statistics could also be generated for specific time periods such as peak/off peak and weekday/weekend; however, the focus here is to provide an overview of what the output looks like and how it might be used by the operator. Positive numbers represent late running, while negative figures indicate that the bus arrived early. For Route A trips observed in the validation files, buses arrived an average of 3 minutes and 59 seconds late to the final stop (ST17). As always, care needs to be taken interpreting output because the numbers may be influenced by one of two outliers. In this case, it can be seen that the maximum value column shows at least one Route A trip was more than 45 minutes late to ST17. Almost all of the maximum values were attributable to this one Route A trip made on a Sunday, which started 7 minutes late and became increasingly late as the trip went on. Before any meaningful analysis can be done with the spreadsheet, it is obviously necessary to search for outliers like these and flag them, or exclude them from the dataset.

## Table 5. Differences Between Scheduled Arrival Times and Actual Times (Inbound Trips)

| Timing Point | Count | Average | Median | Standard Deviation | Minimum | Maximum |
|---|---|---|---|---|---|---|
| ST1 | 49 | 0:02:31 | 0:01:31 | 0:02:56 | -0:00:07 | 0:14:25 |
| ST2 | 50 | 0:01:24 | 0:00:33 | 0:03:28 | -0:02:23 | 0:15:55 |
| ST3 | 50 | 0:00:47 | 0:00:02 | 0:03:26 | -0:02:31 | 0:15:16 |
| ST4 | 50 | -0:00:26 | -0:01:16 | 0:03:36 | -0:04:34 | 0:14:16 |
| ST5 | 50 | 0:01:17 | 0:00:43 | 0:03:46 | -0:04:10 | 0:16:55 |
| ST6 | 50 | -0:00:15 | -0:00:53 | 0:03:44 | -0:05:47 | 0:13:46 |
| ST7 | 50 | 0:00:41 | -0:00:05 | 0:03:26 | -0:06:04 | 0:12:55 |
| ST8 | 50 | 0:00:28 | 0:00:40 | 0:03:23 | -0:06:22 | 0:12:10 |
| ST9 | 50 | 0:00:24 | 0:00:25 | 0:03:16 | -0:05:19 | 0:11:35 |
| ST10 | 50 | 0:01:37 | 0:01:37 | 0:03:33 | -0:05:19 | 0:14:35 |
| ST11 | 50 | 0:03:45 | 0:03:10 | 0:03:51 | -0:02:49 | 0:16:26 |
| ST12 | 50 | 0:03:38 | 0:03:00 | 0:04:00 | -0:03:17 | 0:16:46 |
| ST13 | 50 | 0:04:17 | 0:03:25 | 0:07:30 | -0:05:58 | 0:46:47 |
| ST14 | 50 | 0:05:15 | 0:04:46 | 0:07:47 | -0:06:07 | 0:48:22 |
| ST15 | 36 | 0:02:41 | 0:03:12 | 0:05:18 | -0:09:13 | 0:11:58 |
| ST16 | 42 | 0:02:12 | 0:02:07 | 0:05:18 | -0:10:07 | 0:12:37 |
| ST17 | 50 | 0:03:59 | 0:03:05 | 0:09:10 | -0:11:33 | 0:45:13 |
| TOTAL TRAVEL TIME | 50 | 1:37:10 | 1:38:46 | 0:11:49 | 1:10:30 | 2:10:43 |

The counts shown for each timing point in Table 5 vary because, for some trips, there were no records located within a 50-meter radius of the stop, so it was not possible to perform a timing check. (This means that minimum and maximum values may not always correspond to the same trip, and may differ considerably.) This occurrence was most pronounced in the CBD because of urban canyon effects.

Figure 3 shows the median time differences between scheduled arrival times and actual arrival times. From the limited data observed in the validation process, it can be seen that Route A inbound services experienced their greatest general delays from ST11 to the end of the route. This information could be used by an operator in a number of ways. The first course of action would be to determine the cause of the discrepancies between the scheduled times and the actual running times. Early running is likely to occur when drivers do not stop at holding points when they arrive early, while late running can result from buses starting late, or from traffic congestion along routes. Early running, particularly where headways are half an hour or more, may be more detrimental to service quality than slight delays, because it may result in passengers having to wait for subsequent buses. When bus services are frequent, reliability may be better reflected in the ability to maintain headways, rather adhering to schedules (Strathman et al. 2000). Unless successive buses are fitted with data loggers, it would not be possible to calculate headway ratios from output files generated by this application. This suggests that the system may be most useful for routes with headways of at least 15 minutes or more. If discrepancies between scheduled and actual times are considered large enough, schedulers could adjust the timetable to more accurately reflect actual travel times. In the case of delays, travel time data could be used by bus operators to argue for improvements in traffic management (e.g., bus lanes).

**Figure 3. Differences Between Scheduled Arrival Times and Actual Times (Inbound Trips)**

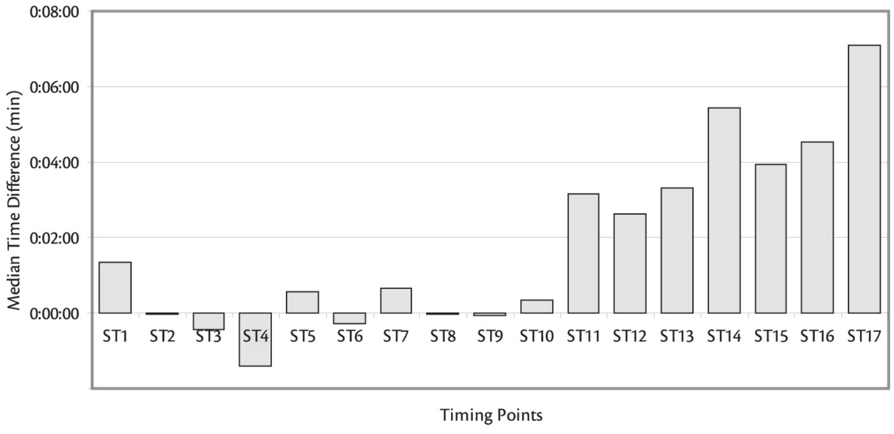
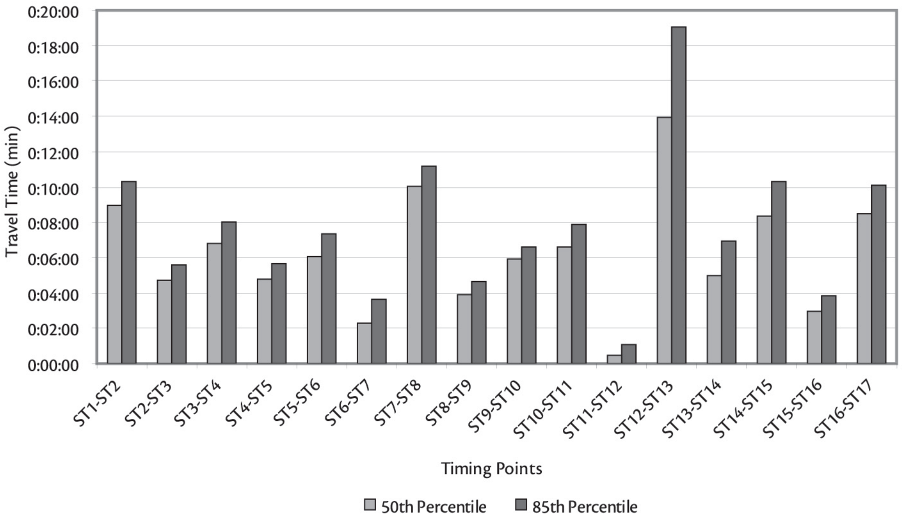


Table 6 provides descriptive statistics for travel times between timing points. A larger set of descriptive statistics is generated for general travel times because these are more commonly used by schedulers than the time differences shown in Table 5. Because good output on travel times has been very difficult to obtain up until now, it is largely unknown which statistic is the best to use for planning schedules. In travel time research literature, median times tend to be favored over averages because they are less sensitive to outliers (Quiroga 1997). For the operator of a transport service, however, a statistic such as the 85th percentile might be more appropriate. Median travel times and 85th percentile times are displayed in the graphical output generated by the spreadsheet, as shown in Figure 4. In general, the 85th percentile times are one to two minutes higher than the median times. Standard deviation is another potentially useful statistic for operators. One of the key advantages of using GPS to collect a large sample of travel times is that it provides information on the variation of travel times across different times and days of the week.

**Table 6. Travel Times Between Timing Points (Inbound Trips)**

| Timing Points | Count | Average | Median | Std. Dev. | Min. | Max. | Cumulative Median Travel Time | Segment Time as % of Total Travel Time | 85th Percentile |
|---|---|---|---|---|---|---|---|---|---|
| ST1 – ST2 | 49 | 0:09:37 | 0:09:25 | 0:01:53 | 0:06:15 | 0:14:30 | 0:09:25 | 10.01% | 0:11:11 |
| ST2 - ST3 | 50 | 0:04:01 | 0:03:58 | 0:01:03 | 0:02:05 | 0:06:25 | 0:13:23 | 4.22% | 0:05:01 |
| ST3 – ST4 | 50 | 0:06:34 | 0:06:30 | 0:00:57 | 0:04:40 | 0:09:53 | 0:19:53 | 6.92% | 0:07:23 |
| ST4 – ST5 | 50 | 0:04:18 | 0:04:13 | 0:01:03 | 0:02:25 | 0:07:10 | 0:24:07 | 4.48% | 0:05:26 |
| ST5 – ST6 | 50 | 0:05:29 | 0:05:33 | 0:00:52 | 0:03:31 | 0:07:34 | 0:29:39 | 5.90% | 0:06:23 |
| ST6 – ST7 | 50 | 0:02:53 | 0:02:42 | 0:01:38 | 0:00:26 | 0:06:35 | 0:32:21 | 2.87% | 0:04:38 |
| ST7 – ST8 | 50 | 0:09:20 | 0:09:07 | 0:01:41 | 0:06:10 | 0:12:48 | 0:41:28 | 9.69% | 0:11:16 |
| ST8 – ST9 | 50 | 0:03:56 | 0:03:48 | 0:00:55 | 0:02:39 | 0:07:05 | 0:45:17 | 4.04% | 0:04:45 |
| ST9 – ST10 | 50 | 0:06:02 | 0:05:58 | 0:01:05 | 0:04:15 | 0:09:33 | 0:51:15 | 6.35% | 0:06:55 |
| ST10 – ST11 | 50 | 0:05:58 | 0:05:50 | 0:01:04 | 0:04:13 | 0:08:44 | 0:57:05 | 6.20% | 0:07:03 |
| ST11 – ST12 | 50 | 0:00:53 | 0:00:31 | 0:00:36 | 0:00:21 | 0:03:15 | 0:57:36 | 0.55% | 0:01:25 |
| ST12 – ST13 | 50 | 0:14:39 | 0:13:36 | 0:04:44 | 0:09:39 | 0:44:01 | 1:11:11 | 14.44% | 0:17:03 |
| ST13 – ST14 | 50 | 0:04:58 | 0:05:02 | 0:01:07 | 0:02:42 | 0:09:25 | 1:16:14 | 5.36% | 0:05:46 |
| ST14 – ST15 | 36 | 0:07:46 | 0:07:44 | 0:00:59 | 0:05:49 | 0:09:39 | 1:23:57 | 8.21% | 0:08:48 |
| ST15 – ST16 | 34 | 0:02:55 | 0:02:47 | 0:00:59 | 0:01:36 | 0:05:45 | 1:26:45 | 2.96% | 0:03:37 |
| ST16 – ST17 | 42 | 0:07:24 | 0:07:22 | 0:01:34 | 0:04:30 | 0:10:50 | 1:34:06 | 7.83% | 0:08:56 |
| TOTAL TRAVEL TIME | 50 | 1:37:10 | 1:38:46 | 0:11:49 | 1:10:30 | 2:10:43 |  |  | 1:46:27 |

Figure 4. Travel Times Between Timing Points (Inbound Trips)



## Cost Effectiveness

From the results of the pilot study, it is estimated that the cost of developing a similar set of tools for 5 to 10 routes operating from a common depot would be in the vicinity of AUD $25,000. Assuming no more than 10 routes are served from a single depot, it would probably only be necessary to invest in two or three data loggers which would be purchased for no more than a total of AUD $4,500 each. Provided units can be easily transferred between buses, the data costs themselves are negligible.

The cost of collecting two hours' worth of running times along a single route using three time keepers would probably be in the vicinity of AUD $180. Assuming that four hours' worth of observations are collected for five routes every two months, the annual costs would total about AUD $10,000 excluding data entry costs. This means that the cost of the software could probably be recovered in two to three years, conservatively. These calculations do not take into account the improved quality of the data collected by GPS, and the fact that many more observations can be collected than manually collected data.

For small operators with only a few short routes, the costs of the system may not outweigh the benefits, particularly if they are operating short feeder services in areas where there is generally very little congestion. The system would probably be most valuable to companies operating buses on long routes (45 minutes upwards), or in areas where traffic delays are encountered.

## Conclusions

This pilot project has shown that it is feasible to collect accurate travel time data using simple, passive GPS devices operating independently of bus drivers and existing on-board computer systems. The approach taken for this project represents a viable, low-cost method for collecting accurate travel time data which can be used to measure on-time running and provide useful data for schedulers. One of the main shortcomings of the GPS devices and GIS processing program described here is that they cannot be easily integrated with other bus systems such as APCs. It is worth noting, however, that it would be possible to link GPS data from the data loggers with ticket sales data from on-board ticketing machines by matching times recorded in both files in a post-processing procedure.

With system development costs aside, the data collection costs associated with the approach taken in this project were very low. Hundreds of hours' worth of data were collected on the study route for little more than the cost of coordinating the movement of data loggers between the depot and head office. The challenge in using GPS to collect travel time data is no longer how accurate data can be collected, but how data can be collected and managed for buses operating in a number of different areas. If anything, GPS can collect too much information, which can make data management and interpretation difficult. Using the portable devices discussed in this article, the operator can control how much is collected.

Overall, portable data loggers appear well suited to measuring travel times and on-time running. It is not necessary to have an entire fleet of buses equipped with GPS to provide information useful to schedulers. With a small investment in just two or three data loggers, it would be possible to implement a continuous survey of many different routes. Data loggers could be rotated through different depots every few weeks and a large travel time database could be built and expanded over time.

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# The Demand Performance of Bus Rapid Transit

*Graham Currie, Monash University*

## Abstract

*This article uses a trip attribute approach to examine the relative passenger attractiveness of Bus Rapid Transit (BRT) systems compared to other transit modes. It examines how passengers value trip attributes for on-street bus, BRT, and light rail and heavy rail systems in passenger behavior research. Empirical data is presented which suggests that passengers value trip attributes for BRT and rail modes in a broadly similar manner. All of these transit modes are favored relative to on-street bus. These findings suggest that BRT systems should be as effective as rail in generating patronage when developed to replace on-street bus services. This conclusion, in association with research demonstrating lower costs for BRT systems compared to rail, may be used to claim cost effectiveness advantages for BRT. However, a number of limitations in the evidence are identified and additional research suggested. Conclusions of the research are also used to suggest ways to improve BRT system design to enhance demand performance.*

## Introduction

Bus Rapid Transit (BRT) is now a major trend in the development of public transport systems worldwide. While BRT has been shown to have lower implementation costs compared to other transit modes (General Accounting Office 2001), its cost effectiveness can only be assessed by examining its relative performance in generating demand compared to other transit modes.

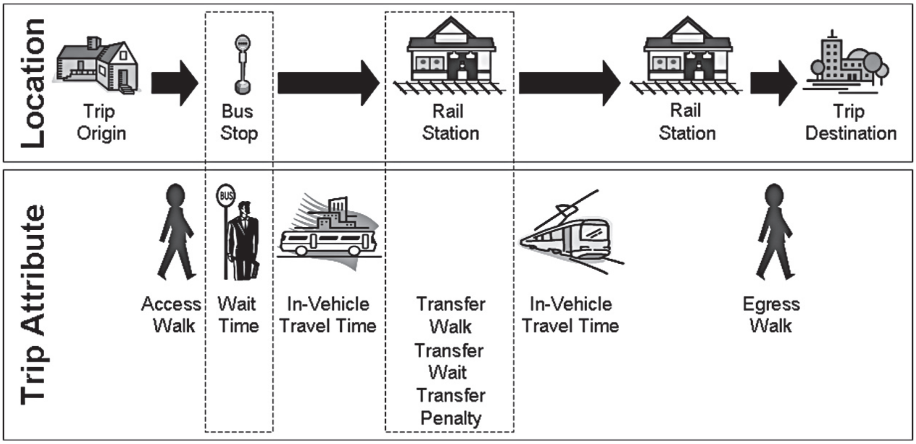
This article explores the relative passenger attractiveness of BRT systems compared to other transit modes by studying trip attribute research evidence. It examines how passengers value trip attributes for on-street bus, BRT, light rail and heavy rail systems in passenger behavioral research and modeling. The article includes:

- a summary of trip attribute research
- an analysis of trip attributes that vary between modes
- an assessment of what the results suggest for the relative attractiveness of BRT compared to other transit modes

## Transit Trip Attributes

Figure 1 shows the key components of a typical trip by public transport.

**Figure 1. Trip Attributes in Typical Transit Journey**



The measurement of how passengers value each of these trip attributes is an important input to disaggregate transport modeling and a major driver of travel demand forecasts for the development of new public transport modes. The quality of travel is measured in terms of generalized cost using a formula of the following type:

$$TGC = ((Walk_t * Walk_w) + (Wait_t * Wait_w) + (IVT_t * IVT_w) + (NT * TP) + MSC_m) * VOT + Fare$$

where:

| | |
|---|---|
| $\text{Walk}_t$ | equals time in minutes walking to and from the transit service |
| $\text{Walk}_w$ | is passenger valuation of walk time to and from transit stops |
| $\text{Wait}_t$ | measures time waiting for transit vehicle to arrive at the transit stop |
| $\text{Wait}_w$ | indicates passenger valuation of wait time at transit stops |
| $\text{IVT}_t$ | shows travel time in transit vehicle/s |
| $\text{IVT}_w$ | is passenger valuation of in vehicle travel time |
| NT | equals number of transfers |
| TP | is transfer penalty |
| $\text{MSC}_m$ | equals mode specific constant for transit mode *m* |
| VOT | measures value of travel time |
| Fare | is average fare per trip |

Primary research measures the values for each of these trip attributes to establish the impacts of new transport investments such as introducing new transit modes. Clearly, modes that have higher perceived generalized cost perform poorly in patronage terms against those with lower values.

It is a central premise of this article that the patronage performance of BRT can best be understood through measurement of how passengers value trip attributes specific to BRT systems. A comparison of how perceived BRT attribute values compare against those of other transit modes will be indicative of their relative patronage performance.

## Trip Attribute Research and Transit Modes

Table 1 divides trip attributes into transit mode neutral and transit mode specific elements based on the degree to which passengers might value the attributes differently for alternative public transport modes.

## Table 1. Mode Specific and Mode Neutral Public Transport Trip Attributes

| **Trip Attribute** | **Description** |
|---|---|
| *Transit Mode Neutral Trip Attributes* | |
| Access walk | Walk from trip origin to transit stop/station |
| Egress walk | Walk from alighting stop to trip destination |
| Wait time | Time at transit stop/station waiting for transit vehicles to arrive |
| Fare | Price of ticket to use service |
| In-vehicle travel time | Time spent in transit vehicle traveling from boarding stop to alighting stop |
| *Transit Mode Specific Trip Attributes* | |
| Transfer penalty | Perceptual value of the need to transfer between one transit vehicle to another |
| Mode-specific factors | Other factors perceived by passengers to vary with transit mode |

It is a common convention in mode choice modeling to make no distinction between transit modes in the measurement of walk and wait time, fare, or in-vehicle travel time (see, for example, Wardman 1997 and Transfund New Zealand 2000).

The research literature also contains many examples in which these trip attributes are measured for several transit modes as a group. Van der Waard (1988), Prosser et al. (1997), and Gwilliam (1999) all quote coefficients for walk and wait times that are aggregates of behavioral evidence from bus, tram, and heavy rail. They are applied to bus, tram, or heavy rail separately, suggesting no expected difference in how a passenger values them between modes.

Public transport fares could vary by transit mode depending on the fares policy and funding approaches of urban transport planning agencies. For purposes of this article, we have assumed fares to be mode neutral since it is the intrinsic differences in the qualities of transit modes that are of interest, not funding policy differences.

Trip attribute factors that are considered to be mode specific include the transfer penalty and mode-specific factors.

## Transit Mode Specific Trip Attributes

### *Transfer Penalties*

The transfer penalty is the perceived value of making a transfer between one public transport vehicle and another. It is the value in addition to any time spent undertaking a walk or wait to complete a transfer. Transfer penalty is expressed as a constant value, usually in terms of minutes of equivalent in-vehicle travel time.

Table 2 shows a range of evidence on the valuation of transfer penalties by transit mode. Although there is much scatter in the data, it is clear that bus-based modes have generally far higher valuations of transfer penalties compared to rail-based modes. The average of the range of bus-bus based transfers is around 22 minutes, which compares with a value for subway-based heavy rail systems of around 8 minutes.

These results might be suggestive of a relatively poor rating for transfers for BRT compared to rail-based modes. However, none of this evidence includes values measured for BRT systems.[1] None could be found in the literature. The bus-based data in Table 2 concerns on-street bus services. Collection of transfer penalties for BRT systems is clearly a research priority. Nevertheless, the data in Table 2 suggest how BRT might perform.

Table 2 shows that transfer penalties are lower for transit modes that have higher quality interchange facilities such as stations, platforms, and protected walkways. Underground subways, which include weather protection, a range of passenger amenities, and facilities such as escalators, tend to have lower transfer penalties. On-street bus services where transfers include waiting in the open air, limited passenger facilities, and can involve crossing roads to complete transfers have higher transfer penalties. These findings are supported by a range of other evidence. For example, Horowitz and Thompson (1994) found that the design of transfer locations could significantly alter passenger perceptions of the transfer penalty. They suggest that the provision of weather protection at transfer locations could benefit passengers by as much as 16 minutes of perceived in-vehicle travel time.

Although a lack of data on transfer penalties is not helpful in establishing BRT's position in relation to other modes, patterns in the available data suggest that BRT should perform well compared to rail-based transit. The development and design of significant station infrastructure is a central theme of BRT-based planning. For example, the Transit Cooperative Research Program (2003a) identifies station infrastructure as a major characteristic of BRT system design. Significant station

## Table 2. Evidence of Transfer Penalty by Transit Mode (Minutes of equivalent in-vehicle travel time)

| | | *Transit Modes* | | | | | |
|---|---|---|---|---|---|---|---|
| *Source* | *Location/ Case* | Bus-Bus | Bus- LRT | Bus-Suburban Rail | Suburban Rail-Suburban Rail | Suburban Rail-Subway | Subway-Subway |
| Charles River Associates (1989)[1] | Chicago/Work Trips | 18-37 | | | | | |
| | Boston/All Trips | | 15-28 | | | | |
| | Ottawa/All Trips | 22-30 | | | | | |
| | Edmonton/All Trips | | 12-25 | | | | |
| | Honolulu/All Trips | 6 | | | | | |
| | Taipei/All Trips | 30 | | | | | |
| British Railways (1989)[1] | London/All Urban Trips | | | | | 10-14 | |
| Ryan (1996)[1] | London | | | | | 5 | 4[3] |
| Standeby (1993)[1] | Oslo | 8-10 | | | | | |
| Piotrowski (1993)[1] | Perth/Work Trips | 8 | | 6 | | | |
| Prosser et al. (1997)[1] | Sydney/A.M. Peak | | | 11 | 6 | | |
| Algers et al. (1975)[2] | Stockholm | 50 | | 23 | 15 | | 4[3] |
| Hunt (1990)[2] | Edmonton | | 18 | | | | |
| Wardman et al. (2001)[2] | Edinburgh | 5 | | | 8 | | |
| Guo and Wilson (2004) | Boston/All Trips | | | | | | 2-32[3] |
| | Average of values | 22 | 19 | 13 | 10 | 9 | 8 |
| | Range of values | 5 to 50 | 12 to 28 | 6 to 23 | 6 to 15 | 5 to 14 | 1 to 32 |

[1] This data sourced from Transfund New Zealand (2000).

[2] This data sourced from Guo and Wilson (2004).

[3] Lower values are explained by short/no walk transfers and cross platform transfers.

*Note:* All values are rounded to the nearest minute infrastructure is identified as a feature of some 21 of the 26 BRT systems examined in the Transit Cooperative Research Program (2003b).

While the above data suggest that BRT systems will have transfer penalties similar to rail-based modes, some caution is required due to lack of primary evidence. In addition Guo and Wilson (2004) have presented evidence that transfer penalties can vary because of the way they are measured. Bus to bus transfer penalties of 4.5, 30, and 49.5 minutes are quoted and shown to derive from alternative approaches to their measurement as well as from different bus systems. Clearly, there is a need for a consistent approach to measurement of transfer penalties as well a need to increase research coverage in relation to BRT systems.

### *Mode-Specific Factors*

The Mode Specific Factor (MSF) is the user-perceived attractiveness of one transit mode compared to another, excluding the influence of factors such as fare, walk time, wait time, in-vehicle travel time, and the need to transfer. The MSF is usually measured as a constant and expressed in minutes of equivalent in-vehicle travel time. The following quote personifies one view of the MSF:

> *Many studies have found that, other things being equal, most public transport users prefer rail to bus because of its greater comfort. To model this choice accurately, a penalty of four to six minutes must often be attached to bus travel to reflect the relative discomfort of buses. Abelson (1995) quoting Fouracre et al. (1990)*

In this case the reference to bus concerns on-street services rather than BRT. Table 3 shows a summary of evidence of the MSF measured in a range of studies. The value of the MSF for heavy rail, light rail, and BRT is indicated. In each case the MSF is expressed as the value of the difference of the transit mode relative to on-street bus. A positive value represents a preference to the transit mode. A negative value represents a preference to on-street bus.

A range of values emerge from Table 3:

- In general, heavy rail is preferred over on-street bus with the value of preferences ranging between 2 minutes and 33 minutes. However, there are a small number of negative values (-5, -27, and -56 minutes). There is an overall average of about 4 minutes preference to heavy rail.

## Table 3. Evidence of Mode-Specific Constants by Transit Mode (Minutes of equivalent in-vehicle travel time)

| *Source* | *Location/ Case* | *Transit Modes* | | |
|---|---|---|---|---|
| | | Bus Rapid Transit vs. On-Street Bus | Light Rail vs. On-Street Bus | Heavy Rail vs. On-Street Bus |
| Halcrow Fox (1995)[1] | Manchester/Car Available Passengers | | 20 | |
| | Manchester/Car Not Available Passengers | | 0 | |
| Bray (1995)/Transfund NZ (2000)[1] | Adelaide/All Trips | 20 | | |
| Ableson (1995)/Fouracre et al. (1990)[1] | International/All Trips | | | 4-6 |
| Van Der Waard (1988)[1] | Holland/All Trips | | 2-3 | 2-3 |
| Kilvington (1991)[1] | UK Several Studies/Car Available Passengers | 9 | 15 | 12 |
| Kilvington (1991)[1] | Dublin/Bus Users | 12 | 16 | 16 |
| London Railplan Review[1] | UK Several Studies/Bus Users | 9 | 8 | 7 |
| Prosser et al. (1997)[1] | Sydney/A.M. Peak | | 4 | 9 |
| Wardman (1997)[2] | Study 19 (B) 1989 | | | -56 |
| | Study 19 (B) 1989 | | | -27 |
| | Study 7 (B) 1992 | | | -5 |
| | Study 4 (B) 1993 | | | 0 |
| | Study 17 (B) 1987 | | | 0 |
| | Study 8 (B) 1988 | | | 3 |
| | Study 20 (B) 1989 | | | 4 |
| | Study 20 (B) 1989 | | | 6 |
| | Study 3 (B) | | | 10 |
| | Study 28 (B) 1989 | | | 11 |
| | Study 28 (B) 1989 | | | 11 |
| | Study 4 (B) 1993 | | | 22 |
| | Study 23 (B) 1990 | | | 33 |
| | Study 13 (B) 1991 | | 1 | |
| | Study 9 (B) 1989 | | 10 | |
| | Study 12(B) 1990 | | 18 | |
| | Average of values | 12 | 10 | 4 |
| | Range of values | 9 to 20 | 2 to 20 | -56 to 33 |

[1] This data sourced from Transfund New Zealand (2000).

[2] The Wardman (1997) evidence is from a series of confidential consultancies studies that are quoted via a code number for reference purposes.

*Note:* All values are rounded to the nearest minute

- All MSF values for light rail showed a preference of light rail over on-street bus ranging from 2 to 20 minutes. The average of the values shown is around 10 minutes.
- All MSF values for BRT systems also display a preference to BRT compared to on-street bus. Values range from 9 to 20 minutes with an average of around 12 minutes.

This evidence is supportive of the case that BRT has generally similar performance to light rail in the perceptions of passengers. Indeed, the average results suggest BRT may perform better than both light and heavy rail. However, the results are both scattered and limited. There are only 4 data points for BRT systems. Heavy rail data are highly skewed by the small number of negative values. Two of the three data points are extreme values and bring down the heavy rail average considerably. Removal of these points would suggest an average of 8 minutes in preference of heavy rail. Inquiries to the data source regarding the validity of these outliers suggested that a wide range of approaches to measurement are being used and may explain variations in results. The results may also be indicative of varied sample size/approach as well as of the circumstances being measured. There is a wide range in the quality and design of transit modes of all types. A run down, poorly designed, slow rail service providing low service levels may well be unfavorably perceived compared with a high-quality bus service, even if it is running on-street. A better comparison of BRT to other transit modes requires a more even-handed approach to the quality of modes being compared. The collation of a larger set of samples and a more uniform approach to measuring mode-specific factors would also improve the quality of the analysis.

It may also be appropriate to examine MSFs from an alternative viewpoint. Table 4 suggests the types of mode attributes that the MSF is representing. In general, ride quality, vehicle design, passenger amenity, and knowledge/understanding of the service offering are the major elements being represented by the MSF.

The attributes in Table 4 are divided into factors that vary with travel distance and one-off or constant value factors. Good ride quality benefits passengers traveling further (i.e., varies with distance traveled), while a quality station is only appreciated once each time it is used (it is a constant factor per trip). A more detailed modeling of mode specific factors might thus be split into mode-specific variables that vary with travel distance and mode-specific constants. This approach was suggested by Halcrow Fox (1995) and matches the views of the consultants in Transfund New Zealand (2000).

## Table 4. Suggested Transit Mode Attributes Measured in MSFs

| *Attribute* | *Definition* | *Comments on Transit Mode Variation* |
|---|---|---|
| **Factors Which Vary with Distance Traveled** | | |
| Vehicle design, ride quality, and comfort | Perceived value of time within the vehicle in terms of ride comfort, ability to read and undertake other activities during the ride | • Heavy rail should have advantage over light rail and BRT due to smoother ride quality and greater internal vehicle space.<br>• Rail and BRT should have a benefit over on-street bus since BRT systems, particularly guided bus systems, have better ride quality than on-street bus. These modes also have less stop/start time due to longer stop distances compared to on-street bus. |
| **Constant Factors** | | |
| Quality of Stations/ Stops | Perception of the quality of the waiting environment at transit stops | • Heavy and light rail and BRT should have similar ratings depending on the extent of quality station design.<br>• All transit modes should perform better than on-street bus, since the quality of the transit stops is better and facilities more substantial with rail and BRT. |
| Knowledge of transit stop location | Perception of where transit stops are located both for boarding and alighting stops | • There is a vast difference in passenger knowledge of the location of rail stations compared to bus stops on street.<br>• The scale of station infrastructure clearly makes it easier to find compared to local bus stops.<br>• This suggests that heavy and light rail and BRT should be perceived broadly equally depending on the scale of the stations involved. On-street bus transit stops should have a lower profile compared to these transit modes. |
| Knowledge of transit route and network design | Perception of where and how transit services operate. The "how and what to use" questions for new travelers. Includes consideration of quality of information provided | • In general, high frequency systems require less timetable information and hence no need to use schedules. In theory, this should have an equal influence for heavy rail, light rail, and BRT, although there is some evidence that BRT systems can have substantially shorter headways on main line busway stations than rail.<br>• Network structure is probably simpler to understand with rail-based systems compared to bus. Most cities have radial rail systems; hence, virtually all city dwellers would know that the railway goes to the CBD. In theory, as long as the profile of BRT or light rail systems is substantial, then they should also be easy to understand.<br>• BRT systems with substantial feeder bus to line-haul busway operations may be more complex to understand. However, similar issues arise for feeder bus networks to rail stations.<br>• Light and heavy rail systems have higher quality passenger information systems than bus. BRT systems with similar quality information systems should have similar demand performance in this regard. |

The analysis in Table 4 suggests that BRT may have at least some weaknesses compared to rail:

- Ride quality should be better with rail systems compared to BRT. However, this may not be true with guided bus systems.
- Rail vehicles can be roomier than bus vehicles.
- Rail systems can be easier to understand due to their simple network structure. However, certainly some of the larger BRT systems have simple system structures which would be as easy to understand as comparable heavy rail systems.

BRT should perform as well as rail with the other factors identified, depending on the scale of the BRT system and the quality of its stations and facilities. Primary research is clearly warranted to further explore these issues.

## Conclusions

This article has sought to investigate the attractiveness of BRT compared to other transit modes from a passenger perspective. It has assembled available evidence on passenger values of trip attributes and how these values vary between transit modes. The perceived valuation of trip attributes has a major influence on passenger demand for transit system performance.

The analysis has suggested that transfer penalties and mode-specific factors are the main trip attributes that vary between transit modes. Empirical evidence has been shown to be limited in quantity and quality. No evidence of transfer penalties for BRT systems was found. However, suppositions based on available transfer penalty evidence suggest BRT systems would perform well compared to other transit modes. Evidence on mode-specific factors also supports this view.

These findings suggest that BRT systems can be as effective in attracting passengers as heavy and light rail. Since BRT has been shown to have significant cost advantages over rail, an overall cost effectiveness advantage may be claimed for BRT.

However, a major finding of this review is the need for additional research to improve the robustness of this analysis. No evidence of transfer penalty research on BRT systems was identified. A high degree of variation in the approaches used to measure transfer penalties was also identified. Adoption of a consistent approach to measure transfer penalties for a range of transit modes would provide a more scientific framework for the comparison of transit modes. The limited number and quality of empirical measures for mode-specific factor measurement were also identified. A more consistent approach for measuring these factors is also supported.

In addition, the article theorizes that mode-specific factors should be split into constant and variable parameters. The performance of all transit modes should be assessed in terms of ride quality, vehicle design, and general perceptions of system route and network knowledge, since these may be potential weaknesses in the design of BRT compared to rail-based systems.

Finally, while this research has sought to explore how BRT might perform from a passenger attractiveness perspective, some of the findings provide useful pointers to good practices in BRT design.

- Passengers dislike transfers. Clearly designs that minimize transferring are more attractive to passengers.
- Transferring is a less significant barrier to travel when quality stations and interchange facilities are provided. BRT design should seek to emulate the quality of heavy and light rail stations in this regard. Cross platform transfers would be an example of good practice.
- The analysis has suggested that the scale of rail transit infrastructure, including stations and rights-of-way, is a significant factor in helping passengers understand how the system operates and also where transit stops are located. BRT systems will have to match the profile, scale, and simplicity of heavy rail systems to be as easy to use and understand as rail systems. The complexity of conventional bus-based systems, in terms of route structure and the large range of services offered, could be a weakness compared to rail. This needs to be addressed to achieve equivalent patronage levels to rail.

In addition, service frequency, travel speeds, and service coverage of BRT systems will need to be as extensive as light and heavy rail systems to match the patronage levels achieved by these modes.

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drafts. Comments from the paper's reviewers are also appreciated. Any errors are, of course, the responsibility of the author.

## Endnote

[1] Some values are provided for bus-bus transfers in Ottawa (Charles River Associates 1989); however, these are for transfers made prior to the full development of the busway network in Ottawa.

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# Innovative Public-Private Partnership Models for Road Pricing/BRT Initiatives

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## Abstract

*This article presents alternative concepts for serving commuter travel demand in major metropolitan areas with a system of priced expressways integrated with Bus Rapid Transit (BRT), and presents potential new models for setting up public-private partnerships (PPP) to finance, implement, and operate the system. These new models may make possible the self-financing of new BRT services and facilitate efficient provision of multimodal transportation services. The PPP model for expressway operation uses shadow tolls to compensate private partners, while at the same time charging motorists market-based tolls to ensure free-flowing traffic conditions and to provide a fast, reliable running way for BRT. Revenues from tolls charged to users may be used to pay contractual obligations to private partners for highway operations, toll collection, and BRT services. To encourage efficient and effective provision of transit, high-occupancy vehicle (HOV, and park-and-ride/pool services, private partners may be compensated for provision of transit services and HOV promotion using shadow fee payments based on the number of commuters served.*

## Introduction

Transportation agencies in major, highly congested metropolitan areas in the United States (with populations in excess of 3 million, such as Washington, DC, or San Francisco) will need to fundamentally rethink the kinds of solutions that make sense. Three forces are causing a change in conventional thinking. First, a precipitous increase in congestion is accompanying growth in jobs, housing, and travel. Second, public resistance to traditional major highway projects continues due to their community and environmental impacts. Finally, many states, local governments, and regional transit authorities face funding shortfalls and do not have the financial resources to address infrastructure needs to serve growing travel demand.

Road pricing includes a group of market-based strategies that all involve collecting a variable toll for highway use, with the primary intent of managing travel demand so as to reduce or eliminate congestion on the priced roadway facility, corridor, or network. There are essentially four pricing concepts that may be employed on a freeway facility to manage traffic and provide a running way that allows Bus Rapid Transit (BRT) to operate with a high level of service:

- *BRT/High-Occupancy Toll (HOT) Lanes.* These are underused high-occupancy vehicle (HOV) lanes which permit non-HOVs paying an electronically charged toll, with excess revenues allocated to transit service. This model operates on the I-15 FasTrak express lanes in San Diego. As proposed, it would be combined with BRT on the I-15 express lanes extension project, with the excess of toll revenues above operating costs supporting BRT service. Construction costs for the extension are tax-financed.
- *BRT/New Priced Lanes.* This includes new priced lanes on existing free roads on segments where no HOV lanes currently exist (Poole and Orski 2003). Only buses and vanpools would get free service. BRT would operate on the express lanes, but funding for BRT would not be supported from toll revenue. In most cases, revenues would not even be adequate to fully pay for costs for constructing the new lanes.
- *BRT/Fast And Intertwined Regular (FAIR) Lanes.* This concept (Eno Transportation Foundation 2002) would convert one or two existing free lanes to priced lanes and provide credits, established at a percentage of the toll rate, for motorists in remaining lanes. The credits would be provided electronically and could be applied to future tolls, public transportation fares, and parking charges at public transportation parking facilities. Since

new construction is limited, surplus revenue would be available to fund BRT services. The concept may also involve adding a new priced lane while converting an existing free lane to a priced lane, for a total of two lanes in each direction. In this case, surplus revenue may not be sufficient to fund BRT services, due to new construction costs.

- *BRT/FAIR Highways.* This concept would convert all lanes on existing freeways to priced lanes, provide toll exemptions for HOVs and discount tolls to low-income motorists, fund BRT, and implement major traffic flow improvements on parallel arterial facilities using Intelligent Transportation Systems (DeCorla-Souza 2003a). The concept may involve adding a new lane while converting the existing freeway to a tollway. In this case, surplus revenue may not be sufficient to fund BRT services fully, due to new construction costs.

Road pricing solutions, although currently novel to members of the public and their elected and appointed governmental officials, will gain acceptance as their real-world performance becomes more widely understood. Meanwhile, Bus Rapid Transit (BRT) is receiving increasing interest as a way to enhance mobility in environments where conventional rail solutions may not be operationally feasible due to dispersed development patterns. In an era of scarce public resources and public resistance to tax increases, road pricing can bring new revenue to make road pricing/BRT projects self-financing, or nearly so. The promise of a steady stream of new revenue from tolls makes it possible to increase private sector involvement in the financing, implementation, maintenance, and operation of such projects for the mutual benefit of both public and private sectors. This article explains the synergy that can be achieved by integrating BRT into road pricing projects, proposes new models for Public-Private Partnerships (PPPs) on Road Pricing/BRT projects, and discusses the benefits to be gained from such PPP models.

## Integrating Road Pricing and BRT

### *Rationale for Market-Based Pricing of Urban Freeways*

Once freeway vehicle density (measured in vehicles per mile) exceeds a certain critical number, both vehicle speed and vehicle flow (measured in vehicles per hour) drop precipitously (Highway Research Board 1966; Transportation Research Board 2000; Chen and Varaiya 2002). Peak-period road pricing can manage travel demand to ensure that critical vehicle density is never exceeded and freeway efficiency and free flow of traffic are maintained. Essentially, a price in the form of a variable toll dissuades motorists from choosing to use a freeway approaching critical density and induces them to shift to carpooling and transit use. They may also shift their route or time of travel, or choose to forego the trip entirely. Solo drivers who arrive when demand is high, pay for the guaranteed congestion-free service electronically. Tolls rise when usage is high to dissuade motorists from congesting the facility. This ensures that vehicle density does not increase beyond the critical level needed to ensure that traffic flow will not break down.

Experience with the variably priced Express Lanes on SR 91 in Orange County, California, has confirmed the ability of road pricing to maximize freeway efficiency. Traffic demand on the express lanes, which became operational in December 1995, is managed using a variable toll. Initially, due to the addition of four lanes in the median, there was little congestion on the regular lanes, since total capacity had increased by 50 percent (two lanes were added per direction to the existing four lanes per direction). However, over the past few years, congestion has increased on the free lanes as demand increased due to development growth in Riverside County, from which most commuters on SR 91 come (Sullivan 2000). While the express lanes have maintained their hourly vehicle throughput in the peak hours, throughput on the free lanes in peak hours has been steadily decreasing.

By early 2004, speeds were 60 to 65 mph on the express lanes, while congestion on the free lanes reduced average peak-hour speeds to no more than 15 to 20 mph. Moreover, the share of vehicles carried in the peak hour on the express lanes had increased to 49 percent, based on traffic volume data provided to FHWA by the Orange County Transportation Authority for the period January 9 through March 25, 2004. Thus, the two express lanes were carrying nearly the same volume as the four free lanes in the same direction. This means that the two express lanes were carrying almost 25 percent of the vehicles per lane. This also means that the remaining four free lanes were carrying only about 12.7 percent of the vehicles per lane. The express lanes were thus carrying almost twice the number of vehicles per lane as were the free lanes. The SR 91 experience demonstrates that pricing ensures efficiency with regard to both throughput and travel speeds on freeways, maximizing return on the public's freeway investment.

As with any market-pricing mechanism, road pricing helps allocate limited supply of road space. With user charges assessed at the point of use, greater efficiency results through improved response to market forces. Under conventional taxation, while users pay for the facilities they use, price signals are not available to balance demand and supply, leading to queuing and congestion. Congestion costs imposed on other motorists by each new motorist on the highway (marginal costs) increase geometrically as traffic volume increases. Pricing is especially effective when marginal costs increase with scale. Road tolls set at marginal cost can significantly decrease congestion costs by dissuading motorists from using highway facilities when the value they derive from highway use (revealed by their willingness to pay marginal cost charges) is less than the marginal costs they impose.

Incremental costs for supply of new road space are also significant. Recent construction cost data suggest that average costs for providing additional peak-period capacity on urban freeways amount to as much $10 million per lane mile (Federal Highway Administration 2000a), which equates to about 32 cents per mile driven on the added lane in peak periods (DeCorla-Souza 2004a). A lower bound of the range of estimates for external costs for air pollution, noise, and crashes is 6 cents per mile driven, based on the lower bound estimate of the nationwide estimates of these costs and vehicle miles of travel (Federal Highway Administration 2000b). Freeway operation and maintenance costs amount to about 1 cent per mile driven. Combined incremental costs for highway supply and externalities associated with peak-period highway use thus amount to about 39 cents per mile. On the other hand, motorists pay fuel taxes amounting to only 2 cents per mile driven. This is calculated based on combined federal and state fuel taxes averaging 40 cents per gallon and fuel efficiency of 20 miles per gallon. Other vehicle charges (e.g., registration fees) amount to less than 1 cent per mile driven (Federal Highway Administration 2003). Highway user charges for peak-period freeway use thus amount to less than 3 cents per mile driven. The difference between motorist fees and incremental costs for roadway supply and externalities associated with peak use of road space is about 36 cents per mile driven. This suggests that an average peak-period toll rate of 36 cents per mile may be justified on urban freeways.

### *Rationale for BRT in Major Travel Corridors*

In the United States, interest in BRT is increasing as an alternative to rail transit due to competitive cost and greater flexibility in serving more dispersed origins and destinations in suburban environments. A key feature of BRT is that it provides frequent, fast, reliable, and identifiable service on a free-flowing lane.

As Lewis and Williams (1999) and Mogridge (1997) have observed, an improvement in high-capacity transit service reduces travel times on all modes in a congested corridor. This phenomenon is known as Mogridge-Lewis convergence. It can be assumed that BRT service on a free-flowing HOT lane would have an impact on travel times on other modes in a congested corridor as well. A free-flowing transit system would attract more riders from the adjacent congested highway as the frequency of the transit service (and therefore the travel time advantage) increases. Travel time equilibrium is reached among the modes, with transit travelers accepting a few extra minutes of travel time probably in exchange for the reduced travel costs associated with transit use. While the capacity of a transit system has some limits, in this situation it can be ignored as a constraint, since additional BRT vehicles can easily be accommodated on the priced lanes.

Priced lanes implemented without BRT attract motorists from congested lanes, improving travel times in the corridor for all modes until the maximum throughput of the priced lanes is reached and the magnitude of the tolls discourages further lane switching. If a BRT line was added to the priced lanes in the same corridor, it would further add person-carrying capacity and permit travel times to continue to improve for even more commuters. An important consideration will be to balance the BRT system's need for service frequency with a conventional toll road franchise's objective of maximizing revenue by maximizing the number of toll-paying vehicles and limiting free service and competition from new person-carrying capacity.

While the BRT/HOT concept is believed to be workable in radial corridors (Barker and Polzin 2004), can it be used in a suburb-to-suburb travel context? Certain factors work against transit use for suburb-to-suburb travel and may keep ridership too low to make high frequency service feasible. These factors include (Newsom, Wegmann, and Chatterjee 1992; Cervero 1993):

- Plenty of free parking at suburban worksites
- Low density development with a dispersed many-to-many trip end distribution
- Lack of a central business district or other activity concentrations
- Urban design that is auto-oriented and unfriendly to pedestrian and transit use (e.g., large building set-backs and wide, high-volume streets)
- Separated land uses with relatively long distances between them
- Higher incomes and auto ownership levels
- An automobile mindset (e.g., one wouldn't move to the suburbs without planning to use an automobile for travel)

In particular, attempts at planning suburban activity centers have resulted in varying degrees of success in creating a transit- and pedestrian-friendly environment

(Filion, McSpurren, and Huether 2000). It is not sufficient to simply have a concentration of high density, mixed-use activity. However, these challenges to transit have not kept very large metropolitan areas from proposing suburb-to-suburb rail transit systems (Gurwitt 2003). BRT could provide similar levels of service while more efficiently addressing access to the line-haul portion of the system. Modeling studies suggest that, when combined with peak-period road pricing strategies, the significant transit travel-time reductions achieved by BRT in highly congested travel corridors may contribute to significant shifts in travel demand from auto modes to BRT (DeCorla-Souza 2003b; DeCorla-Souza 2004b). Even in suburb-to-suburb travel corridors of major metro areas (with major activity centers located along the BRT route), sufficient transit travel demand may be generated to make high-frequency BRT service feasible during the peak-travel periods when tolls are in effect.

### *Synergy with Integration of Road Pricing and BRT*

Road pricing provides two key benefits for BRT:

- By managing traffic demand on a single or multiple freeway lanes to ensure free flow of traffic, road pricing will be able to provide a fixed guideway-like running way for operation of BRT.
- Road pricing generates revenues, which may be used for financing the operation and maintenance of the BRT system as well as to support bonds for capital improvements (stations, park-and-ride facilities, and rolling stock).

BRT, likewise, impacts the feasibility of road pricing in two key ways:

- *Technical Feasibility.* The effectiveness of road pricing strategies increases when motorists have the option of choosing a viable alternative mode. With new BRT service on priced highways, auto travel demand could be reduced without resorting to exorbitant and punitive toll rates to ensure that demand does not exceed levels needed to ensure free flow. Commuters benefit from lower toll rates for those motorists who continue to drive and better transit service for those who choose to use it. The addition of the BRT system should prevent the travel corridor from reaching its person-carrying capacity based on use of the auto mode alone.
- *Political Feasibility.* By keeping toll rates affordable, and by providing a viable alternative for those who may not be willing to pay the toll, BRT increases the public acceptability of road pricing and ensures that equity is preserved for

low-income commuters. Addressing public acceptance and equity concerns is key to political feasibility of road pricing strategies.

## Implementing Integrated Road Pricing/BRT Projects with PPPs

### *Benefits of PPPs*

Procuring transportation facilities and services through PPPs has many advantages over the traditional publicly financed approach (Kopp 1997):

- Projects are generally planned and constructed more quickly.
- Capital demands on the public treasury are reduced.
- Innovation in technology is encouraged.
- Private sector organizations may enjoy significant economies of scale, scope, and experience in the production and management of an international portfolio of projects. Risks may be spread across a diversified spectrum of projects.
- Efficiencies result from exempting private developers from traditional government procurement rules.
- Income is generated for local, state, and national governments from property and income taxes paid by private business.

The federal government, as well as several state and local governments, have shown increasing interest in private sector involvement in the provision of transportation infrastructure and services. Given the innovative aspects of both road pricing as well as BRT, advances in innovation as well as efficiency may be encouraged through greater involvement of the private sector. The following section discusses the issues and suggests a model for PPP agreements that could reduce costs by managing the risks to both public and private sectors.

### *Issues with Regard to Road Pricing*

Pursuit of PPP arrangements for road pricing projects raises some special issues. Efficient freeway operation may occasionally require relatively high charges to keep traffic free flowing during rush hours when travel demand is very high. This may be perceived by the public as price gouging, particularly if revenues and resulting profits go to the private sector. For example, Sullivan (2000) reports that approval of private companies operating a toll road for profit is far lower than approval of tolling itself in the SR 91 corridor in Orange County, California.

In a PPP arrangement, providing for financing of highway investment and operations, it is important to ensure that the public does not perceive that the private sector partner is attempting to maximize profits through excessive peak charges, while the public agency does nothing to relieve congestion on free facilities. This occurred in Orange County, where a noncompete clause in the PPP agreement for the express lanes prevented the public agency from making improvements on the free lanes of SR 91 (Sullivan 2000). Simply eliminating or limiting noncompete provisions is not a solution, because the private sector would be unwilling to invest in highway projects without adequate protection against future competition.

### *A New PPP Model for Road Pricing Implementation and Operation*

To address the issues discussed above, a new model is suggested. It separates the system operator from the revenue beneficiary. The PPP agreement would employ shadow tolls to compensate the private partner. Shadow tolls are usage payments made by a third party. The public agency would pay the private partner a shadow toll based only on the number of vehicles served at free-flow speeds during rush hours, when proactive management of traffic flow with variable tolls is needed. In addition, road users would be charged tolls directly. The private partner would set the user-paid toll rates to manage demand and ensure that traffic is free-flowing (as the express lanes on SR 91). However, all toll revenues would go to the public sector. User-paid toll rates would rise as high as they need to be in order to manage demand effectively, but the private partner would not profit from the resulting increase in user-paid toll revenue relative to shadow toll revenue.

Potential private partners would compete to build and operate the road project on the basis of the quality of their proposals and the shadow toll rates that they are willing to accept as compensation for their infrastructure investments, freeway operation, and toll collection services. Agreements with the private partner will need to include customer service standards (e.g., highway signage, billing, customer service centers), since the private partner could attempt to gain additional profits by reducing quality of service to the public.

If the shadow toll rate negotiated with the private partner is less than the user-paid toll rate, there could be public pressure to reduce user-paid tolls. In this case, it may be relatively simple to demonstrate to the public the advantages of the higher user-paid tolls. For a few days, actual toll rates could be set to match shadow toll rates. The public would then see the resulting effects on overall congestion as well as level of service on the toll lanes. Such an experiment was recently conducted with regard to freeway ramp metering in the Twin Cities metropolitan area in

Minnesota to convince the public of the benefits of ramp metering. There are also many examples of toll facilities employing flat tolls that suffer congestion in peak periods because tolls are not high enough to manage demand in peak periods.

Nevertheless, to ensure the trust of the public, it will still be important to assure them that excess revenues from higher tolls will be used for the benefit of those paying the tolls. Excess revenues could be dedicated to pay for additional transportation services in the corridor. The public is more likely to accept this strategy over the single-service approach used in the initial PPP arrangement for the express lanes on SR 91 (Deakin 1996). This will also assure the public that government will not waste the money (see Figure 4-9 in Sullivan 2000). Sullivan reports that in the SR 91 corridor, more than half the opposition to tolling existing lanes seems related to opposition to government receiving more funds.

## *Benefits of the New Model for Road Pricing*

The new PPP approach for road pricing will reduce public and private risks (and therefore financing costs), deliver services more efficiently and effectively, and maximize mobility. These benefits are discussed below.

### Public and Private Risk

> *Public risk will be greatly reduced* with regard to uncertainty of costs for the innovative technology and operations approaches that will be needed. The public sector would know in advance its maximum cost liability, calculated as the maximum possible vehicle throughput per hour, times the number of peak hours of pricing operations, times the shadow toll per vehicle negotiated with the private partner. The public sector could prepare a financial plan that allocates future receipts from its normal federal, state, and local funding sources to pay for contractual obligations to the private partner. Thus, risks associated with reliance on difficult-to-predict revenues would be minimized.
>
> *Private sector risk would also be reduced, reducing financing costs.* The private partner would be assured of an almost guaranteed stream of revenue based on the negotiated shadow roll rate. This would reduce risk-related costs for financing in the capital markets. For example, risks to bond holders would be reduced, lowering the interest rate demanded. Risk with regard to revenue receipts from user-paid tolls will be borne by the public sector. Therefore, the private partner would not need to be too concerned about the accuracy of

travel growth forecasts, since priced lanes can be guaranteed to be filled to critical density threshold levels simply by lowering the user-paid toll rate.

Also, the private partner would not need to be too concerned about potential effects of competition from possible future improvements that may be made by the public agency on parallel highway facilities. Neither would there be concerns about competition resulting from efforts to improve HOV or transit services. Under normal toll road franchises, these would be of concern because they reduce demand for vehicle use on the tolled facility and the market-clearing price that motorists could be charged. Since the private partner would receive the same monetary reimbursement (i.e., shadow toll) per vehicle, no matter what type of improvements may be made to competing modes and routes, there would be no need in the PPP agreement for a noncompete clause such as the one that led to the termination of the PPP for the express lanes on SR 91 in Orange County, California. If the public partner chooses to improve alternative routes or modes, it absorbs all the risks to user-paid toll revenues.

### Service Delivery and Quality

*Services would be more efficiently delivered.* To maximize its profit, the private partner would strive to keep costs down through innovation, and would use efficient procurement and management practices.

*Services would be more effective.* The private partner would have an incentive to maximize peak-period vehicle throughput, while ensuring that all traffic moves at free-flow speeds. Since the private partner would only be paid for vehicles that are provided with free-flowing premium service, there would be an incentive to ensure that traffic flow does not break down. Should traffic flow disruptions occur (due to accidents, incidents, or repairs), the private partner would be at risk of losing shadow toll revenue and would be likely to clear them as soon as possible. To reduce traffic flow disruptions, the private partner would also be likely to produce innovative solutions to reduce the risk of accidents and the frequency of maintenance operations during rush hours. As on the SR 91 express lanes, a private operator could be required to refund tolls charged to toll-paying motorists who did not get congestion-free service.

Mobility

> *Mobility benefits would be maximized, rather than revenue.* There would be no incentive for a private operator to keep the charges per vehicle high, simply in order to maximize revenue. Higher charges than needed to manage traffic result in mobility losses, as motorists are unnecessarily dissuaded from traveling or are unnecessarily shifted to alternative routes. This is the case with a typical toll road franchise. Tolls are charged during off-peak periods to maximize revenue, even though plenty of capacity may be available on the facility. With the new PPP model, charges would only be as high as needed to ensure efficient free-flowing freeway operation with maximum vehicle throughput. Also, tolls would be unnecessary in the off-peak periods if spare capacity were available, and would not be charged.

## *A New PPP Model for Transit or HOV Services*

A PPP arrangement similar to the concept described above may be used to provide improved transit or HOV services. The private partner would be compensated by the public partner with a base service fee payment plus a usage payment (similar to the shadow toll) for each transit or HOV trip served above a base usage level. This usage payment per trip would make up for the difference between fares and the marginal cost per trip for providing service above the base usage level. With shadow usage payments, the private partner stands to increase its revenues (and potentially, profits) by increasing the use of transit or HOVs. This would increase its incentive to promote transit and HOV use and to maximize their use, resulting in public benefits from reduced roadway usage during peak times.

Shadow usage payments are justified since a significant share of benefits from shifts to transit and HOV modes accrue to the general public and not directly to the user. While transit and HOV commuters may save money over driving solo, they may experience longer travel times, including more onerous walk and wait times. They are constrained as to the time of travel and may not be able to do things they would be free to do if they were driving solo (e.g., eat, drink, smoke, talk for long periods on their cell phones, play loud music of their choice on their car stereo systems). On the other hand, nonusers benefit from lower pollutant emissions, less dependence on foreign oil, less congestion, higher development densities, and other social benefits that accrue from reduced traffic levels.

HOV shadow fee payments and transit shadow usage payments may not be cost-efficient if they exceed the estimated values of external benefits (e.g., the reduction in external costs resulting from solo driver trips eliminated). Therefore, it is important for a public agency to have the capability to estimate the value of changes in external costs resulting from mode shifts. External benefits may be estimated using the *Transportation Research Board's Guidebook to Estimate and Present Benefits and Disbenefits of Public Transit* (ECONorthwest and Parsons Brinckerhoff Quade & Douglas, Inc. 2003). If the bid price from a private partner for shadow fee payments per trip is higher than the marginal external benefit, the PPP contract may not be economically justified.

As in the case of road pricing PPP agreements, private partners could finance transit or HOV investments by going to the capital markets and availing of credit support from the federal government under the Transportation Infrastructure Finance and Innovation Act of 1998 (TIFIA), backed by the projected revenue stream from fares and shadow usage payments. The mix and intensity of transportation options in a corridor may warrant a special taxing district established by the public partner to generate additional funds for shadow usage payments. In addition, the public partner might reduce parking requirements for new or expanded buildings served by BRT with a contribution to the corridor transportation program, in lieu of the expense of expanded parking. Value-capture techniques may be applied, but, in general, the auto-oriented character of most development in freeway corridors is not expected to generate many value-capture opportunities for transit, although it could for highway elements.

### Application of the Model for Transit

> The PPP arrangement for transit would make over-the-road bus service commercially viable for transit travel within the corridor. Minimum transit performance and safety service standards (e.g., service frequency, passenger load factors, vehicle condition) could be set by the public partner to ensure quality of service. Base service payments to be made to the private transit operator could be determined on the basis of the cost of minimum required service level set by the public agency less expected fare revenue, with adjustments allowed for fuel prices. Shadow usage payments for riders above the specified base level of transit ridership would be based on an automatic accounting of the number of riders carried. Accounting would be facilitated by requiring use of electronic fare payment (using a smart card) for anyone wanting to get the subsidized fare.

### Application of the Model for HOV Services

Carpools and vanpools are often perceived as competitors to transit, since the modes have many similar characteristics. A private partner operating transit services would, therefore, be concerned about the risk of competition from any efforts to increase HOV use. To address this issue, the private partner operating transit services would also be under contract to run the HOV promotion program, and would be compensated through a base service fee payment plus a shadow fee per HOV trip above a base HOV usage level (the level of HOV use observed immediately after implementation of the road pricing program).

Protection would be provided for the public partner in the event that unexpected shifts to carpooling occur due to external factors such as a fuel shortage or significant fuel price increase. This could be done by limiting the number of new HOV trips for which it would pay a shadow fee, or by using a fee schedule that decreases as HOV volume increases. Keeping track of the number of HOVs would be relatively easy because each HOV would be identified electronically (such as passing through special lanes upon entry into the priced facilities) in order to receive a toll exemption (DeCorla-Souza 2003a).

Under a conventional toll road franchise, the private operator responsible for the tolled lanes would be concerned about reduced revenues from carpools, if carpools are required to be provided free service. However, this will not be a problem with the PPP model proposed in this article, because the private operator of the priced lanes will be compensated by a shadow toll for every vehicle, whether it is a single-occupant vehicle, HOV, or a transit vehicle.

## *Benefits of the New PPP Model for Transit or HOV Services*

The new PPP approach for transit and HOV service delivery suggested above could be more economically efficient than a conventional service delivery approach, and could encourage service delivery innovation, as discussed below.

### Economic Efficiency

*Economic efficiency and social benefits could be maximized.* The private partner would have an incentive to promote transit use up to the point where the total revenue from the transit fare payment (a proxy for the transit rider's benefit) and the shadow usage payment per trip (a proxy for the external benefit) would be just equal to its marginal costs for providing service. Similarly, the private partner would have an incentive to promote HOV use up to the point where the shadow fee payment per HOV trip (a proxy for the external benefit) would be just equal to its marginal costs for promoting and providing HOV service.  This would maximize economic efficiency and net social benefits.

Shadow fee payment schedules could be designed to cost efficiently maximize the person throughput of the transportation corridor. If the shadow fee payment rates were set carefully, the private partner would be in a position to seek the most socially cost-efficient mode (transit or HOV) with which to serve the commuter. The operator would have an incentive to maximize transit ridership and HOV use in order to maximize its total revenues. Base transit service frequency requirements will ensure that the shadow fee per HOV does not provide an incentive to the private partner to increase HOV use at the cost of transit ridership to such an extent that it results in a significant reduction in transit service frequency, thus compromising the quality of BRT service.

### Service Delivery and Innovation

The incentive to maximize transit ridership, if successful, could lead to more riders and, therefore, more frequent service. All transit riders would gain, because any increase in service frequency will reduce waiting time.

The private partner would also have an incentive to provide additional premium services for those willing to pay a higher fare (e.g., door-to-door limousine services similar to airport shuttles, or vanpool services), provided that the private partner would still be eligible to get the agreed-upon shadow usage payment per rider from the public agency. Private operators would have an incentive to work with Transportation Management Associations to encourage employees to take transit or carpool. They might innovate with such concepts as fare agreements with employers and building owners, provision of additional services and conveniences such as station cars and park-and-ride/pool lots, and TravelSmart marketing programs (Western Australian Department of Transport 2000) that ask people to make voluntary changes in their travel choices and encourage them to use other ways of traveling, rather than driving alone in a car.

## Potential Demonstration Projects

Public trust, understanding and acceptance of the innovative transportation, road pricing, and PPP concepts discussed above may be facilitated with a pilot project. This section discusses three potential candidate pilot projects.

The criteria for selecting a pilot project include those characteristics that will both support roadway pricing and sufficient transit use. For roadway pricing, high volume, congested travel for much of the day is a desirable existing condition. For BRT, as guidance from suburban mobility research suggests (Urbitran Associates, Inc. et al. 1999), criteria may include:

- Real employer support
- Participatory planning and local support
- Congestion and parking fees that make automobile travel less attractive
- High density destinations
- Reasonably populated residential market sheds
- Supportive regional planning
- Transit-dependent populations
- Special rolling stock

Based on the above criteria, three potential pilot projects are identified in the Washington, DC metropolitan area.

### *Dulles Toll Road*

Variable tolls to eliminate congestion may be piloted most easily in an existing congested travel corridor with a tolled freeway. Such an opportunity exists in the Dulles Toll Road corridor in Northern Virginia. The Dulles Toll Road Authority could enter into an arrangement with a private partner to implement dynamic peak-period tolls for single-occupant vehicles (SOVs) to ensure free-flowing traffic conditions.  Surplus revenues could be used to pay private partners or public agencies to provide new or enhanced transit and HOV services in the corridor, including toll discounts for HOVs.

Compensation for dynamic pricing operations would be provided in the form of shadow toll payments for each vehicle provided congestion-free service in the peak period. Compensation for transit and HOV services would be in the form of usage payments based on the number of new transit riders and new HOV commuters. Since availability of parking spaces at park-and-ride/pool facilities can be a limiting factor for these services, the private partner would have an incentive to innovate with new parking arrangements, feeder services, new transit centers, and station cars to maximize transit and HOV use.

### *Interstate 66*

Integrated road pricing/transit strategies may also be demonstrated on I-66 inside the Capital Beltway in Northern Virginia. The facility is currently congested in peak hours, despite being restricted to HOV2+ vehicles. HOV occupancy requirements could be raised back to the original HOV3+ requirement, and HOV2 and SOV use could be permitted with payment of a peak toll that varies to ensure free flow of traffic.

Revenues would go first to pay the private partner for operation of the existing facility during peak periods using the shadow toll concept. Surplus revenues would be dedicated to improve or further subsidize transit service in the corridor, establish new parking arrangements, create new transit centers, set up station cars, pay for feeder services, provide additional parking for transit or HOV riders, and make highway safety improvements.

Since availability of parking is currently the limiting factor at Metro transit stations, private provision of parking facilities may be encouraged through a program that offers private parking providers a subsidy payment for each transit rider who is provided with parking near a Metro station or bus stop at a specified rate below market price. Transit riders would be identified through use of Metro's electronic SmarTrip card. They would need to use SmarTrip to pay for parking as well as transit fares to the park-and-ride or transit station where their cars are parked. This would reveal whether the parker had indeed transferred from a transit vehicle.

### *Capital Beltway*

Applying the concept might be much more difficult in a heavily traveled suburb-to-suburb travel corridor such as the Capital Beltway (I-95/I-475) corridor in Northern Virginia. No HOV lanes currently exist on the Beltway.

A study by the Virginia Department of Transportation and the Federal Highway Administration (2002) and a private sector proposal for new HOT lanes for the Capital Beltway (Fluor Daniel 2003) suggest that costs for constructing new lanes cannot be financed solely from toll revenues, and HOT lane operating costs and any new transit services would need to be supported using tax dollars. Thus, to ensure self-financing capability, it would be necessary to convert one or two existing lanes to BRT/HOT lanes or BRT/FAIR lanes to generate sufficient revenue to support implementation of BRT. However, significant public outreach and education with regard to costs, revenues, and benefits of alternative concepts will need to be conducted before such a concept can be entertained in the political arena.

## Summary

This article has presented alternative concepts for serving commuter travel demand in major metropolitan areas with a system of priced expressways integrated with Bus Rapid Transit. The article has also presented potential new models for setting up public-private partnerships for the delivery of such a system. The models employ outcome-based contracting systems and incorporate financial incentives to maximize public mobility goals, with clear performance standards to ensure service quality. The models address public concerns relating to private sector monopoly power, as well as private sector concerns about competition from alternative modes and highway routes. At the same time, the models facilitate efficient provision of new multimodal transportation services and maximize mobility and freeway efficiency. A pilot demonstration of these models would help considerably in gaining public understanding, trust, and acceptance of these innovative concepts.

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# Review of Urban Transportation in India

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## Abstract

*Cities play a vital role in promoting economic growth and prosperity. The development of cities largely depends upon their physical, social, and institutional infrastructure. In this context, the importance of intraurban transportation is paramount. This article provides an overview of urban transport issues in India. Rather than covering every aspect of urban transportation, it primarily focuses on those areas that are important from a policy point of view. The article first reviews the trends of vehicular growth and availability of transport infrastructure in Indian cities. This is followed by a discussion on the nature and magnitude of urban transport problems such as congestion, pollution, and road accidents. Building on this background, the article proposes policy measures to improve urban transportation in India.*

*Indian cities cannot afford to cater only to private cars and two-wheelers and there has to be a general recognition that policy should be designed in such a way that it reduces the need to travel by personalized modes and boosts public transport system. This requires both an increase in quantity as well as quality of public transport and effective use of demand as well as supply-side management measures. At the same time, people should be encouraged to walk and cycle and government should support investments that make cycling and walking safer.*

## Introduction

The establishment of State Transport Undertakings (STUs)[1] in India in the 1960s and 1970s did an enormous service in linking towns and villages across the country, particularly in the western and southern parts. Even though the service may leave much to be desired in terms of quality, the importance of STUs lies in the fact that, unlike in most other developing countries, one can connect to almost every village in India. Urban areas in India, which include a wide range of megacities, cities, and towns, are not all that fortunate in terms of intracity transportation. Transport in this context has been a victim of ignorance, neglect, and confusion. As far as the public transport system in Indian cities is concerned, dedicated city bus services are known to operate in 17 cities only and rail transit exists only in 4 out of 35 cities with population in excess of one million.

Transport demand in most Indian cities has increased substantially, due to increases in population as a result of both natural increase and migration from rural areas and smaller towns.[2] Availability of motorized transport, increases in household income, and increases in commercial and industrial activities have further added to transport demand. In many cases, demand has outstripped road capacity. Greater congestion and delays are widespread in Indian cities and indicate the seriousness of transport problems. A high level of pollution is another undesirable feature of overloaded streets. The transport crisis also takes a human toll. Statistics indicate that traffic accidents are a primary cause of accidental deaths in Indian cities. The main reasons for these problems are the prevailing imbalance in modal split, inadequate transport infrastructure, and its suboptimal use. Public transport systems have not been able to keep pace with the rapid and substantial increases in demand over the past few decades. Bus services in particular have deteriorated, and their relative output has been further reduced as passengers have turned to personalized modes and intermediate public transport.

Individual cities cannot afford to cater only to private cars and two-wheelers. There must be a general recognition that without public transport cities would be even less viable. There is a need to encourage public transport instead of personal vehicles. This requires both an increase in quantity as well as quality of public transport and effective use of demand as well as supply-side management measures. People should also be encouraged to use nonmotorized transport and investments may be made to make it safer. Cities are the major contributors to economic growth, and movement in and between cities is crucial for improved quality of life.[3]

## Vehicular Growth and Modal Split

In 2002, 58.8 million vehicles were plying on Indian roads (Table 1). According to statistics provided by the Ministry of Road Transport & Highways, Government of India, the annual rate of growth of motor vehicle population in India has been about 10 percent during the last decade. The basic problem is not the number of vehicles in the country but their concentration in a few selected cities, particularly in metropolitan cities (million plus). It is alarming to note that 32 percent of these vehicles are plying in metropolitan cities alone, which constitute about 11 percent of the total population. During the year 2000, more than 6.2 million vehicles were plying in megacities (Mumbai, Delhi, Kolkata, and Chennai) alone, which constitute more than 12.7 percent of all motor vehicles in the country (Table 2). Interestingly, Delhi, which contains 1.4 percent of the Indian population, accounts for nearly 7 percent of all motor vehicles in India.

### Table 1. Total Number of Registered Motor Vehicles in India: 1951–2002 (in Thousands)

| Year | All Vehicles | Two-Wheelers | Cars, Jeeps, and Taxis | Buses | Goods Vehicles | Others |
|---|---|---|---|---|---|---|
| 1951 | 306 | 27 | 159 | 34 | 82 | 4 |
| 1961 | 665 | 88 | 310 | 57 | 168 | 42 |
| 1971 | 1865 | 576 | 682 | 94 | 343 | 170 |
| 1981 | 5391 | 2618 | 1160 | 162 | 554 | 897 |
| 1991 | 21374 | 14200 | 2954 | 331 | 1356 | 2533 |
| 1999 | 44875 | 31328 | 5556 | 540 | 2554 | 4897 |
| 2000 | 48857 | 34118 | 6143 | 562 | 2715 | 5319 |
| 2001 (P) | 54991 | 38556 | 7058 | 634 | 2948 | 5795 |
| 2002 (P) | 58863 | 41478 | 7571 | 669 | 3045 | 6100 |

Source: Transport Research Wing, Ministry of Road Transport & Highways, Government of India, New Delhi. Motor Transport Statistics of India. Various issues.

Note: P indicates provisional; Others include tractors, trailers, three-wheelers (passenger vehicles), and other miscellaneous vehicles that are not separately classified.

### Table 2. Total Number of Registered Motor Vehicles in Selected Metropolitan Cities in India: 1995–2000 (Year as of March 31 and Number of Vehicles in Thousands)

| Metropolitan Cities | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 |
|---|---|---|---|---|---|---|
| Ahmedabad | 510 | 572 | 631 | 686 | 739 | 799 |
| Bangalore | 796 | 900 | 972 | 1130 | 1332 | 1550 |
| Chennai | 768 | 812 | 890 | 975 | 1056 | 1150 |
| Delhi | 2432 | 2630 | 2848 | 3033 | 3277 | 3423 |
| Hyderabad | 557 | 764 | 769 | 887 | 951 | N.A. |
| Jaipur | 368 | 405 | 449 | 492 | 542 | 598 |
| Kolkata | 561 | 588 | 588 | 664 | N.A. | N.A. |
| Mumbai | 667 | 724 | 797 | 860 | 911 | 970 |
| Nagpur | 198 | 213 | 239 | 270 | 298 | 331 |
| Pune | 358 | 412 | 468 | 527 | 568 | 593 |

Source: Transport Research Wing, Ministry of Road Transport & Highways, Government of India, New Delhi. *Motor Transport Statistics of India*. Various issues.

Note: N.A. indicates unavailability of data.

Traffic composition in India is of a mixed nature. A wide variety of about a dozen types of both slow- and fast-moving vehicles exists. Two-wheelers[4] and cars (including jeeps) account for more than 80 percent of the vehicle population in most large cities. Analysis of data presented in Table 3 reveals that, during the year 2000, personalized vehicle population share was more than 90 percent of the total vehicle population in 6 out of 13 sample cities. The share of buses is negligible in most Indian cities as compared to personalized vehicles. For example, two-wheelers and cars together constitute more than 95 percent in Kanpur and 90 percent in both Hyderabad and Nagpur, whereas in these cities buses constitute 0.1, 0.3, and 0.8 percent, respectively.

**Table 3. Private and Public Transport Vehicles in Selected Metropolitan Cities in India (as of March 31, 2000)**

| Metrolpolitan Cities | Two-wheelers | Cars (including jeeps) | Taxies (including auto-rickshaws) | Buses | Others | Total |
|---|---|---|---|---|---|---|
| Ahmedabad | 616738 | 104179 | 43865 | 14993 | 19316 | 799091 |
| Bangalore | 1164204 | 238374 | 77375 | 6380 | 63362 | 1549695 |
| Chennai | 848118 | 207860 | 45016 | 4409 | 44223 | 1149626 |
| Delhi | 2184581 | 869820 | 104747 | 37733 | 226593 | 3423474 |
| Hyderabad | 757684 | 99314 | 48898 | 2539 | 42189 | 950624 |
| Jaipur | 444889 | 76133 | 12513 | 14362 | 49760 | 597657 |
| Kanpur | 273208 | 323212 | 5252 | 882 | 23556 | 626110 |
| Kolkata | 298959 | 238560 | 41946 | 8586 | 75995 | 664046 |
| Lucknow | 344268 | 53069 | 15454 | 2816 | 26779 | 442386 |
| Mumbai | 407306 | 325473 | 156261 | 15414 | 65226 | 969680 |
| Nagpur | 272734 | 27573 | 10666 | 2788 | 17478 | 331239 |
| Patna | 184585 | 40357 | 16302 | 3785 | 30989 | 276018 |
| Pune | 443266 | 62885 | 44590 | 7827 | 34046 | 592614 |

Source: Transport Research Wing, Ministry of Road Transport & Highways, Government of India, New Delhi. *Motor Transport Statistics of India*. Various issues.

Note: Others include goods vehicles, tractors, trailers, and other miscellaneous vehicles that are not separately classified; figures for Hyderabad and Kolkata are for 1999 and 1998, respectively.

Table 4 presents the existing modal split in terms of percentage of trips made on different modes across Indian cities. When compared with the desirable level of modal split (Table 5), it was found that the share of mass transport is well below the desired range, whereas the share of personalized transport and paratransit is already above the optimal range in most Indian cities. Unfortunately, the modal split does not appear to be moving in the right direction. For example, share of mass transit in Delhi has stayed at the same level for the last two decades (Table 6).

## Table 4. Existing Modal Split in Indian Cities (as a % of Total Trips)

| City Population (in millions) | Walk | Mass Transport | IPT | | Car | Two-wheeler | Bicycle | Total |
|---|---|---|---|---|---|---|---|---|
| | | | Fast | Slow | | | | |
| 0.10–0.25 | 37.1 | 16.4 | 10.4 | 20.1 | 3.3 | 24.1 | 25.7 | 100.0 |
| 0.25–0.50 | 37.8 | 20.6 | 8.9 | 17.2 | 2.6 | 29.8 | 20.9 | 100.0 |
| 0.50–1.0 | 30.7 | 25.4 | 8.2 | 12.0 | 9.5 | 29.1 | 15.9 | 100.0 |
| 1.0–2.0 | 29.6 | 30.6 | 6.4 | 8.1 | 3.3 | 39.6 | 12.1 | 100.0 |
| 2.0–5.0 | 28.7 | 42.3 | 4.9 | 3.0 | 5.0 | 28.9 | 15.9 | 100.0 |
| 5.0+ | 28.4 | 62.8 | 3.3 | 3.7 | 6.1 | 14.8 | 9.4 | 100.0 |

Source: Ministry of Urban Development, Government of India, New Delhi. 1998. *Traffic and Transportation Policies and Strategies in Urban Areas in India*. Final Report.

Note: IPT denotes intermediate public transport vehicles such as taxies and three-wheeler autorickshaws.

## Table 5. Desirable Modal Split for Indian Cities (as a % of Total Trips)

| City Population (in millions) | Mass Transport | Bicycle | Other Modes |
|---|---|---|---|
| 0.1–0.5 | 30–40 | 30–40 | 25–35 |
| 0.5–1.0 | 40–50 | 25–35 | 20–30 |
| 1.0–2.0 | 50–60 | 20–30 | 15–25 |
| 2.0–5.0 | 60–70 | 15–25 | 10–20 |
| 5.0+ | 70–85 | 15–20 | 10–15 |

Source: Ministry of Urban Development, Government of India, New Delhi. 1998. *Traffic and Transportation Policies and Strategies in Urban Areas in India*. Final Report.

Table 6. Modal Split Trend in Delhi

| Mode | Modal Split (in percent) | | | |
|---|---|---|---|---|
| | 1969 | 1981 | 1986 | 1994 |
| Bus | 41 | 62 | 62 | 62.0 |
| Car | 59 | 38 | 38 | 6.9 |
| Two-wheeler | | | | 17.6 |
| Bicycle | | | | 6.6 |
| Cycle rickshaw | | | | 3.5 |
| Others | | | | 3.4 |

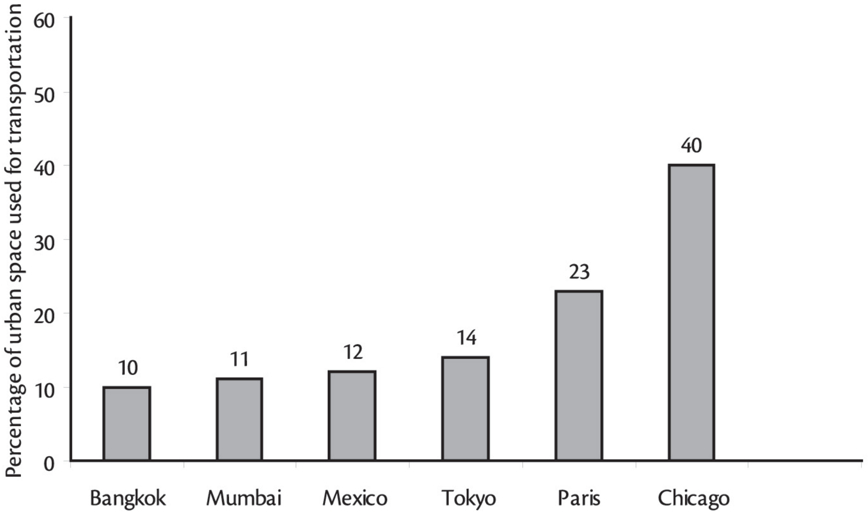
Source: Singal 2000.

## Transport Infrastructure in Indian Cities

The area occupied by roads and streets in Class I cities (population more than 100,000) in India is only 16.1 percent of the total developed area, while the corresponding figure for the United States is 28.19 percent. Interestingly, even in Mumbai, the commercial capital of India, the percentage of space used for transportation is far less when viewed in comparison to its counterparts in the developed world (Figure 1). In general, the road space in Indian cities is grossly insufficient. To make the situation worse, most of the major roads and junctions in Indian cities are heavily encroached by parked vehicles, roadside hawkers, and pavement dwellers. As a consequence of these factors, the already deficient space for movement of vehicles is further reduced.

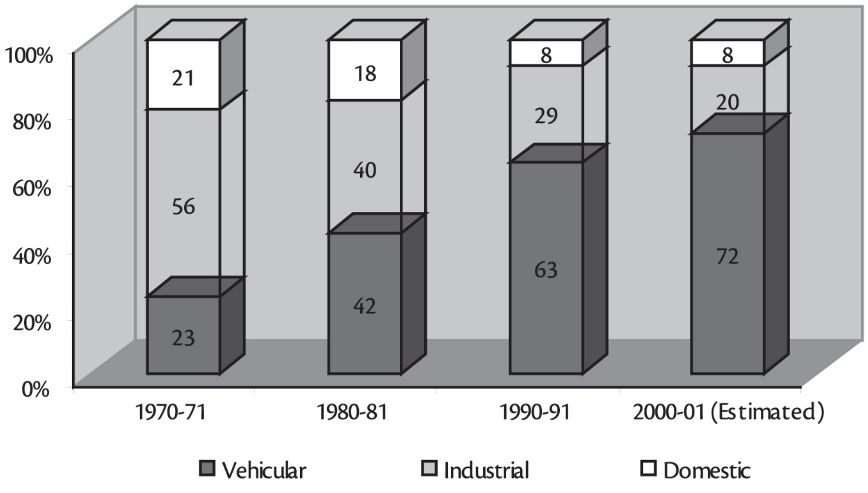
The present urban rail services in India are extremely limited. Only four cities (Mumbai, Delhi, Kolkata, and Chennai) are served by suburban rail systems. Rail services in these four main cities together carry more than 7 million trips per day. The Mumbai Suburban Rail System alone carries about 5.5 million trips per day. A few other cities also have limited suburban rail systems but they hardly meet the large transport demand existing in these cities.

## Figure 1. Allocation of Urban Space for Transportation in City Centers



Source: Amsler 1996.

## Figure 2. Air Pollution in Delhi by Sources



Source: Planning Department, Government of NCT of Delhi, March 2000.

A few metropolitan cities are served by well-organized bus services. Services are mostly run by publicly owned State Transport Undertakings (STUs). Private bus services operate mainly in Delhi and Kolkata. All passenger buses use the standard truck engine and chassis; hence, they are not economical for city use. There are virtually no buses in India specifically designed for urban conditions. Qualitatively, available urban mass transport services are overcrowded, unreliable, and involve long waiting periods. Overcrowding in the public transport system is more pronounced in large cities where buses, which are designed to carry 40 to 50 passengers generally, carry double the capacity during peak hours. As a result, there is a massive shift to personalized transport, especially two-wheelers, and proliferation of various types of intermediate public transport modes (three-wheeler auto-rickshaws and taxies).

## Vehicular Emission, Congestion, and Road Safety Issues

The transport sector is the major contributor to air pollution in urban India. For example, 72 percent of air pollution in Delhi is caused by vehicular emission (Figure 2). According to studies by the Central Pollution Control Board (CPCB) of India, 76.2 percent of CO, 96.9 percent of hydrocarbons, and 48.6 percent of NOx are caused by emissions from the transport sector in Delhi. The ambient air pollution in terms of Suspended Particulate Matter (SPM) in all metropolitan cities in India exceeds the limit set by the World Health Organization (WHO) (Sharma and Mishra 1998). For example, in Kolkata, the average annual emission of SPM is 394 microgrammes per cubic meter, while the WHO standard is 75. With deteriorating levels of mass transport services and increasing use of personalized modes, vehicular emission has reached an alarming level in most Indian cities.

Indian cities also face severe traffic congestion. Growing traffic and limited road space have reduced peak-hour speeds to 5 to 10 kms per hour in the central areas of many major cities. This also leads to higher levels of vehicular emission. According to the Centre for Science and Environment (CSE), the quantity of all three major air pollutants (namely, CO, hydrocarbons, and nitrogen oxides) drastically increases with reduction in motor vehicle speeds. For example, at a speed of 75 kmph, emission of CO is 6.4 gm/veh.-km, which increases by five times to 33.0 gm/veh.-km at a speed of 10 kmph. Similarly, emission of hydrocarbons, at the same speeds, increases by 4.8 times from 0.93 to 4.47 gm/veh.-km. Thus, prevalent traffic congestion in Indian cities, particularly during peak hours, not only increases the delay but also increases the pollution level.

India is also facing serious road accident problems. According to the Ministry of Road Transport & Highways, during 2001, nearly 80,000 people were killed in road accidents. In the last decade, road accidental deaths increased at a rate of 5 percent per year. Although annual rate of growth in road accidental deaths in Indian cities is a little less than 5 percent, these areas face serious road safety problems. For example, four Indian megacities constitute 5.4 percent of all road accident-related fatalities, whereas only 4.4 percent of India's population lives in these areas. Table 7 presents road accidental casualties in selected metropolitan cities in India. In 1997, the latest year with available statistics, the number of accidents in 10 metropolitan cities was 74,073 with 6,293 fatalities. In the same year, the Delhi metropolitan region, where motor vehicle ownership reached 2.8 million, recorded nearly 11,000 traffic accidents, 21 percent of which were fatal. Analysis of data from a selected sample of cities shows that from 1990 to 1997, the number of fatalities is increasing at the rate of 4.1 percent per year—which is quite high by any standard. The accident severity index (number of fatalities per 100 accidents) was also found to be very high for all cities other than Ahmedabad, Bangalore, Kolkata, and Mumbai.

## Table 7. Road Accidental Casualties in Selected Metropolitan Cities in India

| Metropolitan Cities | 1990 Fatalities | 1990 Accidents | 1990 ASI | 1997 Fatalities | 1997 Accidents | 1997 ASI |
|---|---|---|---|---|---|---|
| Ahmedabad | 195 | 2873 | 7 | 239 | 3229 | 7 |
| Bangalore | 562 | 6729 | 8 | 704 | 8722 | 8 |
| Chennai | 507 | 5877 | 9 | 749 | 5171 | 14 |
| Delhi | 1670 | 7697 | 22 | 2342 | 10957 | 21 |
| Hyderabad | 276 | 1412 | 20 | 377 | 2108 | 18 |
| Jaipur | 235 | 1062 | 22 | 303 | 2022 | 15 |
| Kolkata | 463 | 10911 | 4 | 471 | 10260 | 5 |
| Mumbai | 400 | 25331 | 2 | 401 | 27421 | 1 |
| Nagpur | 166 | 1139 | 15 | 387 | 1496 | 26 |
| Pune | 275 | 1387 | 20 | 320 | 2687 | 12 |

Source: Road Safety Cell, State Transport Authority, Cuttack, Orissa, India, March 2003. *Compendium on Road Accidents–2003.*

Note: ASI = accident severity index (defined as number of fatalities per 100 accidents).

Table 8 presents pedestrian and bicycle fatalities as a percentage of total road accident fatalities in selected countries and cities. This table clearly shows that pedestrians and bicyclists constitute a larger proportion of road crash victims in India than in any other sample countries. Because there is little provision of transport facilities to separate the motor vehicle traffic from cycle rickshaws, bicycles, and pedestrians, nonmotorized transport vehicles and pedestrians face a higher risk of traffic accidents in Indian cities. The urban poor, who are more likely to travel either on foot or by nonmotorized transport modes than the nonpoor, face higher traffic accident risks. A serious attempt must be made to either make public transport available to them through targeted subsidization or to make the road safer to cycle and walk.

**Table 8. Pedestrian and Bicycle Fatalities as a Percentage of Total Road Accident Fatalities**

| City/Country | Pedestrian | Bicycle |
|---|---|---|
| Delhi, India (1994) | 42 | 14 |
| Bandung, Indonesia (1990) | 33 | 7 |
| Colombo, Sri Lanka (1991) | 38 | 8 |
| China (1994) | 27 | 23 |
| Australia (1990) | 18 | 4 |
| U.S.A. (1995) | 13 | 2 |

Source: Mohan 2002.

## Policy Measures to Improve Urban Transportation in India

### *Focusing on Bus Transport*

Passenger mobility in urban India relies heavily on its roads. Although rail-based transport services are available in a few megacities, they hardly play any role in meeting the transport demand in other million plus cities. Considering the financial health of various levels of governments (central, state, and local) and the investment required to improve the rail-based mass transport system, it is evident that bus transport will have to play a major role in providing passenger transport services in Indian cities in the future. It is amply clear that among the various modes of road based passenger transport, bus occupies less road space and causes less pollution per passenger-km than personalized modes (Table 9). Therefore, urban transport plans should emphasize bus transport.

**Table 9. Pollution Rate and Congestion Effect of Private and Public Transport Vehicles**

| Type of Vehicle | Average Passenger per Vehicle | Pollution Load in gm/pass.-km | Congestion Effect in in PCU/Pass. |
|---|---|---|---|
| Two-stroke two-wheeler petrol engine | 2 | 7.13 | 0.375 |
| Four-stroke two-wheeler petrol engine | 2 | 4.76 | 0.375 |
| Car with catalytic converter petrol engine | 4 | 0.93 | 0.25 |
| Bus with diesel engine | 40 | 1.00 | 0.075 |

Source: Agarwal 2001.

Note: PCU = Passenger Car Unit where 1 car = 1 PCU, 1 bus = 2.5 PCU, 1 scooter = 0.75 PCU, etc.

There is need for a great variety of bus transport services in Indian cities. Given the opportunity, people reveal widely divergent transport preferences, but in many places city authorities favor a basic standard of bus services. It is often thought to be inegalitarian to provide special services, such as guaranteed seats or express buses, in return for higher fares. In other words, variety is usually curbed. Government regulation and control have exacerbated the poor operational and financial performance of publicly owned urban transport undertakings, which are the main providers of bus transport services in Indian cities. As cost of operation rises, transport systems come under financial pressure to raise fares, but politicians are under pressure to keep fares at existing levels. Unless the system is subsidized, it has to eliminate some of its less profitable or loss-making services. In a democracy, politicians are bound to yield to pressures from those whose services are threatened and to insist on maintaining money-losing operations. Due to this, transport undertakings find it difficult to raise their revenue sufficiently enough to meet the cost of operation.[5] In addition, they have to provide concessional travel facilities to various groups, such as freedom fighters, journalists, students, besides paying a high level of different kinds of taxes.[6] It is becoming increasingly difficult for loss-making urban transport undertakings to augment and manage their fleet, which in turn leads to poor operational performance and deterioration in quality of services.

With few exceptions, publicly owned urban transport undertakings in India operate at higher unit costs than comparable transport operations controlled by the private sector. Kolkata provides an opportunity to make a direct comparison between privately owned and publicly owned bus systems. Public buses are operated by the Calcutta State Transport Corporation (CSTC), with a fleet size of more than 1,250 buses and staffing ratio per operational bus of 11. CSTC has also been plagued by fare evasion estimated at more than 15 percent of revenue. As a result of low productivity and fare evasion, the system requires a huge subsidy since revenues cover less than half of the costs.[7] On the other hand, there are 1,800 private buses in the city. These buses are operated mainly by small companies or individual owners grouped into a number of route associations. Fares for private and public bus services are the same. Despite the similarity in fare rates, private operators have been able to survive financially without any subsidy. Their success is attributed to high levels of productivity, which are reflected in low staffing ratios and high fleet availability. Private bus operators in Kolkata, who hold almost two-thirds of the market, play a major role in meeting the demand and thus substantially reduce the financial burden on the state government. Furthermore, publicly owned urban transport undertakings often lack the flexibility of organization, the ability to hire and fire staff, or the financial discretion needed to adapt to changing conditions. In such circumstances, a policy that encourages private participation in the provision of bus transport services should be welcomed. There is an urgent need for restructuring of the public transport system in Indian cities to enhance both quantity as well as quality of services.

### *Enhancing Transport Coordination*

There is an urgent need for a transportation system that is seamlessly integrated across all modes. The various modes of public transport, including intermediate public transport, have to work in tandem. They should complement rather than involve themselves in cutthroat competition. Presently, different agencies, independent of each other, are operating different services in Indian cities. For example, in Delhi, metro rail is operated by Delhi Metro Rail Corporation Ltd, suburban rail service by Northern Railway, bus transport service by Delhi Transport Corporation, and taxi and auto-rickshaw by private operators. There is a lack of coordination among these agencies. Since the ultimate objective is to provide an adequate and efficient transport system, there is a need to have a coordinating authority with the assigned role of coordinating the operations of various modes. This coordinating authority may be appointed by the central or state government and may have representatives from various stakeholders such as private taxi operators, bus operators, railways, and state government. The key objective should be to attain the integration of different modes of transport to improve the efficiency of service delivery and comfort for commuters. At the same time, a single-ticket system, where commuters can buy a transport ticket that is valid throughout the public transport network within the coordinating authority's jurisdiction, should also be developed and promoted.

### Restraining the Use of Polluting Vehicles and Fuels

Most of the two- and three-wheelers in India operate with two-stroke engines, which emit a high volume of unburnt particles due to the incomplete combustion. Similarly, many new diesel cars have come up in the market, primarily because diesel is priced is far less than petrol in India. Government encourages this price differential mainly to help farmers and bus and truck operators. This price benefit is not meant to be available for personal cars. Although diesel cars emit less greenhouse gases, there are serious concerns about the public health effects of their particulate matter (PM) emissions in densely populated metropolitan cities.

Government should use market-based instruments to promote cleaner technology and fuel. For example, a relatively high annual motor vehicle tax, which may be increasing with the age of vehicle, can be imposed on two-stroke two-wheelers and all vehicles that are more than 10 years old. Similarly, cars that use diesel could be discouraged in million-plus cities by levying tax on diesel in those cities. Congestion pricing, parking fees, fuel taxes, and other measures could be used to restrain the use of all personalized modes. Emphasis should be on the use of market-based instruments as opposed to a command-and-control regime.

### Demand-Side Management Measures

In general, Indian cities have not made much progress in implementing demand-side management measures, such as congestion pricing and parking fees. Although policy measures that involve restraining the use of private cars and two-wheelers are likely to be unpopular, a gradualist approach of progressively introducing restraints on road use, while at the same time improving public transport, is more likely to lead to greater acceptance. Improved public transport and more efficient management of demand would help to combat the trend away from public transport vehicles and toward greater use of personalized modes.

### *Supply-Side Management Measures*

Supply-side measures, such as one-way traffic, improvement of signals, traffic engineering improvements for road network and intersections, and bus priority lanes, should be introduced in all cities, especially in metropolitan cities, so that existing road capacity and road-user safety are increased. These may be considered short-term measures. Road infrastructure improvement measures, like new road alignments, hierarchy of roads, provision of service roads (e.g., bypasses, ring roads, bus bays, wide medians, intersection improvements, construction and repair of footpaths and roads, removal of encroachments, and good surface drainage) should also be introduced in million-plus cities. These can be considered medium-term measures. Besides short- and medium-term measures, there is a need to have long-term measures as well, involving technology upgrades and the introduction of high-speed, high-capacity public transport systems particularly along high-density traffic corridors.[8]

### *Encouraging "Green" Modes*

An urban transport strategy should also encourage the need for developing "green" modes, such as bicycles, cycle rickshaws, and pedestrians. First of all, the safety concerns of cyclists and pedestrians have to be addressed adequately. For this purpose, there has to be a segregated right-of-way for bicycles and pedestrians. Apart from improving safety, this will help improve traffic flow, increase the average speed of traffic, and reduce emissions resulting from low speeds. To enable longer trip lengths on bicycles, bicycle technology should be improved. Lighter bicycles with gears and tubeless tires would be ideal for longer trips. The government can promote the development and commercialization of lighter, more efficient bicycles.

### *Need to Strengthen Urban Institutions*

Most Indian cities have failed to address transportation problems effectively, mainly because they are not equipped with the appropriate institutional capacity and required financial resources. This is because functional responsibilities for urban transport are fragmented among central, state, and local level governments where no one entity is in charge of overall coordination. Management of urban areas is primarily a responsibility of the state governments in India. However, several key agencies play an important role in urban transport planning work under the central government, with no accountability to the state or local government. Central government is directly involved in the provision of suburban rail service through Indian Railways in four megacities. The Indian Ministry of Road Transport

& Highways is responsible for national highways, including the stretches within urban areas, and local governments have no role in the operation and management of these stretches though they are heavily used for urban transport.

State governments independently control local land-use policies, motor vehicle and sales tax rates, bus transport systems, and policies for private sector participation. Most of the local governments at the municipal level rely heavily on capital grants from the states for almost all infrastructure projects. Although Urban Local Bodies (ULBs) have been empowered by the Constitution (74th Amendment) Act of 1992 to assume responsibilities for development of urban transport, most of them do not have adequate power to raise financial resources.[9] Their revenue comprises mainly intergovernmental transfer from the state, property tax revenues, and octroi. The first two are the major sources of revenue for most ULBs. However, octroi is a major source of revenue for some of the ULBs in the state of Gujarat, Maharashtra, Orissa, Punjab, and Manipur. ULB revenues are barely sufficient for salaries and current expenditures, and most capital investments are funded through borrowing, often from the state Urban Infrastructure Development Corporations (UIDCs). Revenues from user charges imposed on publicly provided infrastructure services are minimal.

Although the 74th Amendment aimed to provide administrative and fiscal decentralization at the local government level, progress in this regard has been slow primarily because local governments are still dependent on higher levels of governments for funding. They do not have the power to raise additional tax revenue and are still dependent on intergovernmental transfer arrangements. Since most of the state governments in India are currently in fiscal difficulty, and some even in crisis, urban transport financing has been affected by state fiscal difficulties. In addition, local governments lack the capacity to generate their own revenues. As long as this situation continues, most cities will not be able to improve their transport infrastructure. There is a pressing need to empower the ULBs to raise funds for developmental projects in urban areas on their own, rather than being dependent on the states. Also, they should be authorized, through legislation, for overall coordination of activities relating to the provision of transport infrastructure by various government agencies in their respective urban areas.

## Conclusions

Transport systems are among the various factors affecting the quality of life and safety in a city. The urban transport situation in large cities in India is deteriorating. The deterioration is more prevalent in metropolitan cities where there is an excessive concentration of vehicles. Commuters in these cities are faced with acute road congestion, rising air pollution, and a high level of accident risk. These problems cannot be solved without a concise and cogent urban transport strategy. The main objective of such a strategy should be to provide and promote sustainable high-quality links for people by improving the efficiency and effectiveness of the city's transport systems. Policy should be designed in such a way as to reduce the need to travel by personalized modes and boost the public transport system. At the same time, demand-side as well as supply-side management measures should effectively be used. People should be encouraged to walk and cycle and government should support investments that make cycling and walking safer. Finally, there is a need to empower the Urban Local Bodies to raise finances and coordinate the activities of various agencies involved in the provision of transport infrastructure in urban areas.

## Endnotes

[1] Publicly owned STUs in India provide bus transport services in almost every state of the country. During the year 2000–01, they operated with about 115,000 buses. As bus transportation is a state subject in India, they are owned and operated by respective state governments.

[2] The urban population in India has increased significantly from 62 million in 1951 to 285 million in 2001 and is increasing at a rate of 3 percent per year from last two decades. Consequently, the number of metropolitan cities with a population exceeding one million has increased from 5 in 1951 to 35 in 2001.

[3] The role of cities in the national economy has been growing in importance, as the share of urban areas in Gross Domestic Product (GDP) has grown from 50 percent in the early 1990s to 60 percent in 2000. Fast-growing cities in India have nurtured business and industry and have provided jobs and higher incomes. Thus, it is important that cities function efficiently.

[4] Two-wheelers include motorcycles, scooters, and mopeds. They are usually petrol-driven vehicles and available in both two- as well as four-stroke engines. Although engine capacity of two-wheelers in India varies from 60 cc for mopeds

to 535 cc for motorcycles, most of them operate with an engine capacity of about 100 cc.

[5] During the year 2001–02, publicly owned urban bus transport undertakings in India incurred an accumulated loss of about Rs. 5310 million which is equivalent to a loss of Rs. 4.25 per bus-km.

[6] During the year 2001–02, on average, every bus operated by urban bus transport undertakings in India paid Rs. 53,000 in the form of motor vehicle tax, passenger tax, etc.

[7] CSTC incurred a total cost of Rs. 1498 million whereas its total revenue was around Rs. 627 million during the year 2001–02.

[8] Capital-intensive projects should be considered if and only if they are absolutely necessary. In many cases, instead of building underground railways or elevated highways, the government would have done better to have increased the capacity of existing bus services. Careful appraisal of capital-intensive projects should be performed before implementing them.

[9] States are expected to devolve adequate powers, responsibilities, and finances upon the ULBs so as to enable them to prepare plans and implement schemes for the development of urban areas. However, responsibility for giving it a practical shape rests with the states. States are expected to act in consonance with the spirit of the act for establishing a strong and viable system of local self-government.

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