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Welfare and Equity Impacts of Gasoline Price Changes under Different Public Transportation Service Levels

Aaron Golub
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Abstract

The impacts on public transit ridership of changes in gasoline prices and service levels have been studied, while the combined effects of gasoline price changes under different levels of transit service have not. This paper discusses a consumer welfare calculation based on a binary mode choice model for commuters in idealized corridors with varying public transportation levels of service. Welfare losses are seen to be greatest for commuters in corridors with poor public transit options, and losses increase with rising gas prices. Low-income commuters are seen to suffer more welfare loss in corridors with low-performing transit options than in corridors with well-performing public transit systems. This simple model points to the need for more research regarding the impact of high gas prices on low-income households' commute behavior and access to jobs.

Introduction

In the Phoenix metropolitan area, for most trips, door-to-door travel times by public transportation can be three to five times as long as by automobile. The transit mode share for work trips there is less than half of that of the U.S.—

2.3 versus 4.8 percent (U.S. Census Bureau 2005-2007). Even travelers from most of the poorest households are “captive” drivers, having few other reasonable travel options. A total of 6.2 percent of households have no vehicles, much lower than metropolitan areas of similar size, such as Baltimore (11.4%), Philadelphia (13.6%), and Boston (12.5%) (U.S. Census Bureau 2005-2007). Generally speaking, then, the increase in gas price likely represents a more significant welfare loss from the population in Phoenix than in the other cities, since the choice to avoid payment is not a reasonable option for most. An interesting set of questions arises: How would losses in cities with poor public transit options compare to the losses for commuters in cities with better transit options? Would low-income and high-income commuters suffer similar losses? Would low-income households suffer less in a city with better transit options? This paper explores these questions using an existing binary mode choice model to analyze different commuting mode choice scenarios with changing gasoline prices. Before proceeding to our analysis, the context for this area of questioning is further discussed.

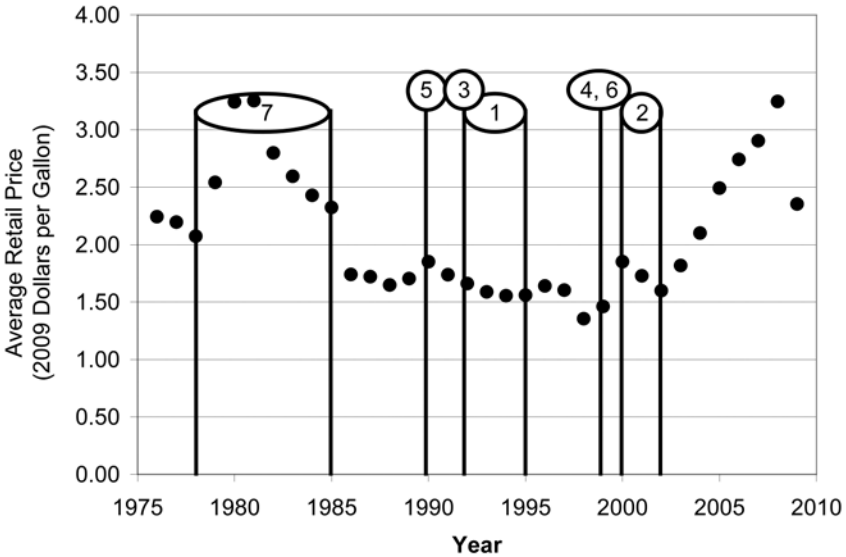
Gas Prices and Low-Income Travel

Concern for low-income workers’ access to jobs has been a central one in urban research over the past half-century, especially as it relates to metropolitan decentralization (the spatial-mismatch hypothesis), welfare reform, and access to transportation. Access to jobs is indeed found to be influenced by access to transportation. Some work emphasized the role public transit systems could have in providing needed access to overcome the spatial-mismatch problem (Sanchez 1999), while many studies questioned these conclusions. Taylor and Ong (1995) and Gurley and Bruce (2005) emphasized the importance of automobile access in explaining job accessibility, renaming the spatial mismatch as one of “automobile mismatch.” Others confirmed the “automobile mismatch” conclusion and questioned public transit’s effectiveness for job accessibility compared to the automobile (Ong and Blumenberg 1998; Wachs and Taylor 1998). Cervero et al. (2002) and Sanchez et al. (2004) found that public transit access was largely insignificant in affecting employment likelihoods for former welfare recipients.

The review of the Spatial Mismatch research by Ihlanfeldt and Sjonquist (1998) shows that none of the studies incorporated out-of-pocket costs as an element of transportation costs; costs were either spatial or temporal. Rogers (1997) found that the results for employment access predictions are sensitive to the specification of accessibility models, however. If this is the case, could a rise in gasoline prices add significantly to time costs that were thought to be the main component

of travel costs? This issue may not have mattered during the periods of historically-low gasoline prices, but prices are unlikely to remain as stable or as low in the future (EIA 2009). Figure 1 shows the dataset years for the job access research superimposed on annual average gasoline prices in the U.S. Note that gasoline prices were below \$2 per gallon (2008 dollars) from 1985 to 2005, the period during which a bulk of the job access research was performed.

Thus, the question should be asked: How might rising marginal costs of automobile operation affect job access? Clearly, ownership costs are significant barriers to overcome for low-income households. Now, with rising or volatile gasoline prices, marginal costs may become more significant and affect the ability to use vehicles for commuting. This adds a new dimension to the mismatch problem of accessibility cost and may impact employment outcomes, resulting policy emphases, and the “automobile mismatch” conclusion. These issues are explored in this paper using several choice scenarios to model the impacts gasoline prices may have on commute mode choice and the welfare of low-income commuters.



Key to studies: 1: Cervero et al. 2002; 2: Gurley and Bruce 2005; 3: Ong and Blumberg, 1998; 4: Ong, 2002; 5: Sanchez, 1999; 6: Sanchez et al., 2004; 7: Taylor and Ong, 1995 (Energy Information Agency, 2010)

Figure 1. Dataset year for spatial mismatch studies focused on transportation mode superimposed on annual average unleaded gasoline prices, 1975 to 2009

Study Approach

Some hypotheses concerning the interaction between welfare, transit service levels, income, and fuel prices can be stated *a-priori*: under rising fuel prices, welfare losses in places with poor transit options will be greater than in places with good transit, low-income populations will suffer more as a share of income, and low-income households will suffer less in places with better transit options. While these conclusions may seem obvious, no studies have addressed these simple questions.

In this paper, these interactions between transit service, income and fuel prices are explored by developing commute scenarios and comparing their modeled welfare changes. For an example choice utility function and representative 10-mile commute, the choice model calculates choice and welfare changes under changing gasoline prices. Three models are set up for three public transit “levels of service,” representing, loosely, a commute trip in a corridor with few reasonable transit options; a corridor with reasonable transit options compared to driving where access, travel times, and out-of-pocket costs are competitive; and a corridor where public transit access and travel times are significantly faster than driving options. First, the specific performance assumptions and choice model are presented. Next, the scenarios are evaluated for commuters of different income levels to compare how welfare impacts differ for them under the different level of transit service scenarios. Before proceeding to the scenarios, previous work concerning the interactions between welfare, fuel prices and mode choice is reviewed.

Background

The National Research Defense Council (David Gardiner & Associates 2007) alluded to the idea of connecting transit quality with the impacts of fuel price changes when they sought to identify which U.S. states’ drivers were most “vulnerable” to oil dependency, measured by the share of the residents’ incomes spent on gasoline. The most vulnerable states tended to be more rural, such as Mississippi, or had large urban areas with few public transit options, such as Georgia and Arizona. The least vulnerable states, such as New York and Massachusetts, have large cities with well-performing public transit systems. While such aggregate measures lose the detailed connection between mode choice and transportation characteristics, they point to a connection between urban form, transit quality, and gasoline price impacts on economic welfare.

The two underlying issues of interest here are the interactions between gasoline price and mode choice, and the estimation of welfare changes resulting from these price and mode choice changes. The impacts of various cost factors such as parking, fuel, and transit fare prices on transit ridership are well studied (Bhat et al. 2009; Litman 2004; Mattson 2008; Taylor and Fink 2003; Wang and Skinner 1984). Cross-elasticity estimates for transit ridership due to gasoline price differ in the short and long timeframes and by type of transit technology (Mattson 2008). Estimates of short-run elasticities typically fall below 0.15, while longer-run estimates ranged from 0.12 to 0.4 (Mattson 2008).

The issue of gas price effects on ridership within a context (though unspecified) of transit quality is brought up indirectly by two recent studies by Currie and Phung (2007) and Haire and Machemehl (2007). Currie and Phung (2007) estimated the ridership elasticity with respect to gas price based on national total ridership data while removing new system expansions from their dataset. They find ridership elasticities for bus, light rail and heavy rail to be 0.04, 0.27 and 0.17, respectively. Using a different approach, Haire and Machemehl (2007) estimate the same three elasticities (actually correlations) to be 0.24, 0.07, and 0.27. Instead of using national data, they focus on five large cities: Atlanta, Dallas, Los Angeles, San Francisco, and Washington, D.C.

It may be difficult to determine exactly why such opposing results were found, but they do point to some interaction between transit quality and mode choice under changing fuel prices. Looking at the results for bus, the cities' in the Haire and Machemehl (2007) study have substantial bus systems with service levels which may enable a realistic alternative for large segments of the population, resulting in a larger choice response to gas price changes. For the national data used in Currie and Phung (2007), it may be that bus systems do not, nationally, offer good choice options, and so elasticities were found to be especially low. Understanding the differences in the rail elasticities would take a more specific analysis of the systems studied.

Numerous studies have estimated welfare impacts from price and choice changes in transportation policy realms (Hau 1987; Mannering and Hamed 1990; Niskanen 1986; Small and Rosen 1981; Pines and Sadka 1984). Several studies use analytical welfare calculations to find that welfare in general falls as prices rise. Pines and Sadka (1984) developed a simple analytical urban commute model that combines gas prices and congestion tolls to show that increasing gas prices reduce welfare, and that congestion tolls should be reduced in order to remain optimal. Similar

results are found for the case of Iranian domestic gasoline consumption under rising gasoline prices (Ahmadian et al. 2007). Hau (1987) looked at different transit levels of supply and their effects on consumers' welfare, but did not test changing gas prices as an independent variable.

Methodology

The approach here is to model user economic welfare before and after gasoline price changes. The calculation is made for three corridor "scenarios" representing different levels of public transit service relative to automobile level of service. The welfare changes of commuters of different income levels are calculated and compared under the three scenarios. Note that this approach is not based on empirical or analytical work, but uses an existing choice model to analyze idealized choice scenarios and welfare impacts. These welfare calculations are described here, followed by the construction of the three corridor scenarios.

Welfare Calculation

In the microeconomic model of mode choice, consumers of transportation derive satisfaction, or "utility," from each of the mode choices available to them. For consumer n , the utility derived from mode choice i , can be represented as $V_{in}(X_{in}, Z_n)$, where V is called the indirect utility function, X_{in} are attributes of the mode and the particular trip (such as fare or travel time), and Z_n are consumer's socioeconomic characteristics (such as age or income) (Ben-Akiva and Lerman 1985). The "compensating variation" (CV) is a standard estimate of welfare change resulting from a policy change (Hanemann 1999). The logit discrete choice formulation conveniently contains the expected maximum utility derivable from a choice set

through the "log-sum" (denominator) term, $\ln \sum_{i=1}^I \exp(V_{in})$, for consumer n ,

where i is the index of choices in the choice set. The standard derivation of the CV within the logit discrete choice formulation effectively calculates the difference between the expected utilities with and without a policy intervention (Small and

$$E[CV_n] = \frac{1}{\lambda_n} \left\{ \ln \sum_{i=1}^{I^1} \exp(V_{in}^1) - \ln \sum_{i=1}^{I^0} \exp(V_{in}^0) \right\}, \quad (1)$$

Where, λ_n is the marginal utility of money for consumer n , and where **1** and **0** are the "states" with and without the policy intervention, such as a price change, respectively (Small and Rosen 1981). State **0** here is when the gasoline price is at the base of \$2 per gallon, and other states are as gasoline prices rise. (See Hau

(1987) for a more complete discussion comparing this and other welfare change measures within the discrete choice framework.)

Dividing by the marginal utility of money converts units of “utils” (the measure between brackets in equation [1]) into units of money. The CV produces an average welfare change per trip in units of $1/\lambda$, or money, per trip. This is the main welfare change calculation. Dividing these average welfare changes into the gas price increase per trip gives reveals what fraction of the gas price change is “passed through” to the average commuter. In a system with no alternative to the automobile, the fraction “passed through” would always equal 1. To understand the difference in effects across income groups, different λ s are used to correspond to the different income groups, since it is a common finding is that λ is a strong function of income (Jara-Diaz et al. 1989; Morey et al. 2003; Morey et al. 2003a).

The calculation assumes that total sum of demand from all modes is fixed, since we are modeling the choice and expected welfare for one trip and need to keep the trip rates equal for the needs of the CV calculation. In reality, some travel will be forgone as prices rise.

Mode Choice Model

A binary mode choice model between automobile and public transit was used to keep the choice mechanism simple. A mode choice estimation adapted from Ben-Akiva et al. (1985) was used to provide reasonable utility function coefficients. The coefficients, shown in Table 1, result from a study performed in Washington, D.C. in 1968 by Cambridge Systematics (Ben-Akiva and Lerman 1985). The marginal utilities of money (bus and auto out-of-pocket costs) were updated from 1968 to 2008 values using the CPI. The updated values of time equal roughly \$4.79 for in-vehicle time and \$16.47 for access time per hour. (Values using the transit cost disutility were slightly higher.) While this simple model includes only automobile and bus modes, it will be used only to illuminate relationships and not to predict any specific ridership changes in corridors with more complex transit options.

The marginal utility of auto out-of-pocket costs (B_4) from the utility function was used as the overall marginal utility of money for the CV (i.e. λ_n) calculation. In the cases where different income levels are explored, different λ s are used, to be explained shortly.

Table 1. Utility Function Coefficients for Binary Mode Choice Model

Coefficient	Auto	Bus	Comment
B1	1.454	0	Constant offset
B2	-0.00897	-0.00897	In-Vehicle Time (min)
B3	-0.0308	-0.0308	Access Time (min)
B4	-0.00187	0	Auto Out of Pocket Cost (cents)
B5	0	-0.00115	Transit Out of Pocket Cost (cents)
B6	0.77	0	Household auto ownership Dummy (for auto only)
B7	-0.561	0	CBD Dummy - 1 if work is downtown, 0 otherwise (for auto only)

Corridor Scenarios

The corridor scenarios are idealized commute scenarios represented by parameters developed by the author based on reasonable assumptions. The parameters used to represent the levels of service for automobile and bus in the corridors scenarios are presented in Table 2. A one-way, 10-mile commute is used as the representative trip. The “Low-Transit” (herein called “Low”) scenario is a case where the trip by automobile is much faster than by public transit. The “Medium-Transit” (herein called “Medium”) scenario represents a case corridor where travel times are similar for the two modes and mode shares are fairly balanced. In the “High-Transit” (herein called “High”) scenario, transit performance is higher than automobile, where congestion and parking add to the costs of automobile commuting. Automobile fuel economy varies by scenario since travel speeds and efficiency will differ by levels of congestion.

While the mode choice model was originally estimated for bus and automobile only, the high-transit scenario represents a level of performance probably only achievable with a rail-like bus service, such as bus rapid transit. We assume that the choice process between these higher performance transit options and automobile retain the same characteristics.

Note that the scenarios represent corridors where automobile levels of service and public transit levels of service result from the long-term development of the corridor. The scenarios are entirely different, where automobile levels of service are good with low congestion and inexpensive parking, and transit service is minimal. Likewise, in corridors with heavy congestion and high parking costs, there are competitive public transit services. The significant differences among the three corridors help to illustrate the interactions between price, choice, and welfare.

After an analysis of these scenarios, the impacts of incremental policy changes on the “Low” scenario are discussed.

Table 2. Input Values for the Three Corridor Scenarios

Variable	Low- Transit “Low”	Medium- Transit “Medium”	High- Transit “High”
One-Way Trip Length (miles)	10	10	10
Automobile Fuel Economy (miles per gallon)	25	20	15
Gallons Used (calculated from fuel economy)	0.40	0.50	0.67
Transit Fare (cents)	150	150	150
Automobile Parking Price (dollars)	0	5	10
Automobile In-Vehicle Speed (mph)	30	20	15
Automobile In-Vehicle Time (calculated from speed)	20	30	40
Transit In-Vehicle Speed (mph)	10	20	30
Transit In-Vehicle Time (calculated from speed)	60	30	20
Automobile Access Time (min)	5	10	10
Transit Access Time (min)	25	10	5
CBD Dummy	1	1	1
Automobile Ownership Dummy	1	1	1

Comparing Welfare Changes for Different Incomes

It is understood that the marginal utility of money declines with rising incomes (resulting, in effect, from higher values of time, etc). Here, low-income commuters were represented by doubling and high-income commuters were represented by halving the marginal utilities of money (parameters B4 and B5) of the middle-income commuters. The three scenarios were then run separately for these three different consumers.

Model Limitations

There are many limitations of such a simple scenario model. The model treats only marginal effects. Some commuting costs are “lumpy,” such as parking and transit passes, which may temper their value in daily decision making. There also may be significant second-order effects, such as a change in subsidy or taxation needed to provide for changing demand for public transportation. Similarly, it is assumed that fuel prices and congestion are exogenous to the system being modeled. That is, rising gasoline prices, which lead to a falling demand for automobile travel, do not feed back to stabilize prices. Likewise, falling automobile demand does not feed back into lowered congestion and travel times.

Temporal issues also are not represented. The lag between gasoline price changes and mode choice changes, the length of time a new mode is used, and the interaction between these temporal issues and the quality of the transit options are not represented.

Drivers also may have other options to reduce welfare losses by changing the way they commute. For one, they may chain trips en route to work, join a carpool, or avoiding motorized travel by telecommuting, cycling, or walking. In the longer term, they may purchase more efficient vehicles or move closer to work. In this way, this simple model of a single constrained commute trip represents an upper bound on welfare losses.

While the age of the choice model may lead to a question of its validity, the simple scenario analysis here depends mainly on the basic utility relationships and tradeoffs between time and out-of-pocket costs, which are likely fairly stable. For example, as shown below, the elasticities of demand for transit with respect to gasoline price are around 0.1 to 0.3, right in the range found in the literature. (For a discussion of the transferability of choice models between times and places, see McFadden and Talvitie (1977, pp 393-394.)

Results: Welfare Changes Across Scenarios

Figure 2 shows the predicted mode choices for the three scenarios as gas prices rise. As expected, automobile mode share is very high and remains fairly static as gas prices rise under the Low scenario. The Medium scenario sees some mode choice shift, though the High-Transit scenario shows the most flexibility as automobile mode choice declines by nearly 1/3 over the range of gas prices. Transit ridership elasticities for the three scenarios are 0.15, 0.23, and 0.28 for the High, Medium and Low scenarios, respectively.

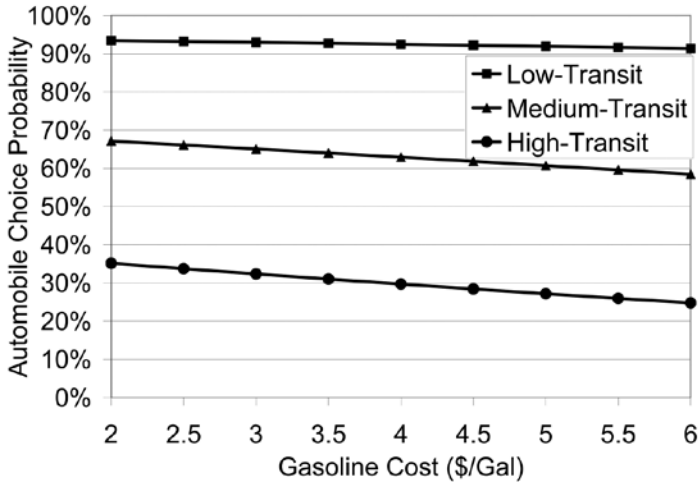


Figure 2. Automobile mode choice for the three scenarios

Figure 3 shows the predicted welfare changes for the commuter for the three scenarios as gas prices rise. Welfare losses are highest under the Low scenario, since gas prices affect nearly all of the average commuters, and few can switch to transit without major increases in travel times. The Medium scenario sees smaller losses, and the High scenario shows the least losses of the three. Interestingly, the Medium and High scenarios still show significant losses because the lower fuel efficiency for drivers means that gas price changes affect remaining drivers more than in the Low scenario. Nonetheless, at \$6 per gallon, the welfare losses of the average commuter living in a corridor with excellent transit are 46 percent less than for the commuter with poor transit options.

It is evident that the Low scenario “passes through” the highest fraction of the gas price increase of the three scenarios (Figure 4). These fractions track closely with the automobile mode shares, but do not decline because of the higher fuel use (lower fuel economy) in the Medium and High scenarios.

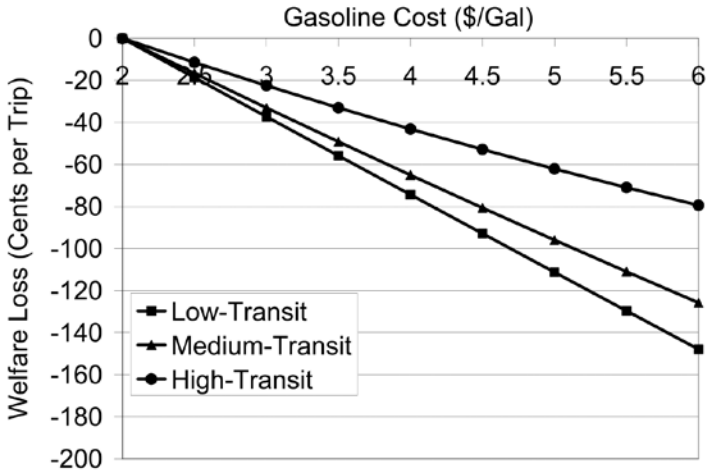


Figure 3. Welfare changes for the three scenarios

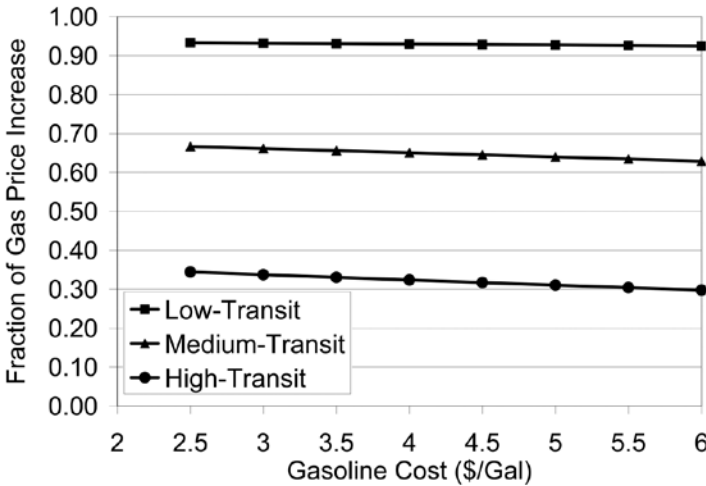


Figure 4. Fraction of price increase passed through to average commuter for the three scenarios

Results: Welfare Changes for Different Income Levels

Here mode choice, welfare change, and gas price “pass-through” will be compared for three income levels between the Low, Medium and High scenarios.

Mode Choice

Automobile mode share remains high and static as gas prices rise for all three income groups (Figure 5[a]) under the Low scenario. The imbalance in modal performance creates few outlets for any of the income groups to escape higher gas prices. Even though the low-income commuter is more willing to switch to transit because of higher cost sensitivities, the low quality of transit service prevents most from doing so.

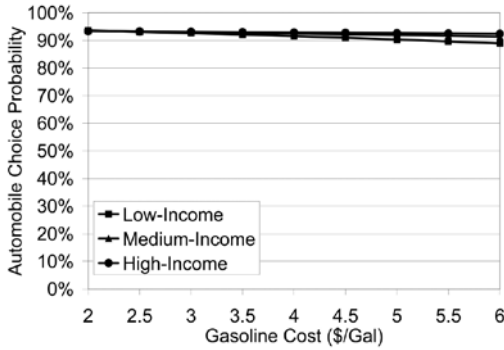
Figures 5(b) and 5(c) show automobile mode shares for the Medium and High scenarios, respectively. In both scenarios, high-income commuters are much more likely to drive, but all three groups switch in significant numbers to transit as gas prices increase. The low-income group, already heavily transit users at low prices, end up cutting their automobile use by over 30 percent when gasoline reaches \$6 per gallon.

Welfare Changes

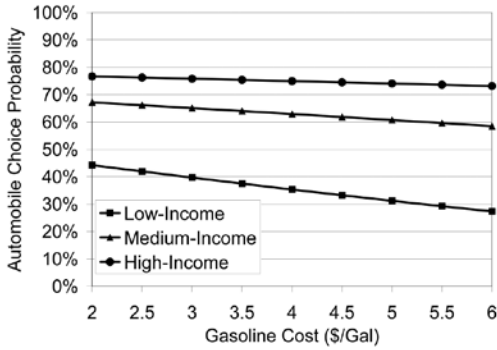
Under the Low scenario, similarly to mode shares, all three income groups lose substantial welfare as gas prices rise (Figure 6[a]). There is a very small separation between groups at high prices as some low-income travelers switch to transit. Under the Medium and High scenarios, low-income commuters more readily avoid gas prices increases by using transit and are affected less than the higher income groups who remain driving (Figures 6[b] and 6[c]).

Gas Price “Pass-Through”

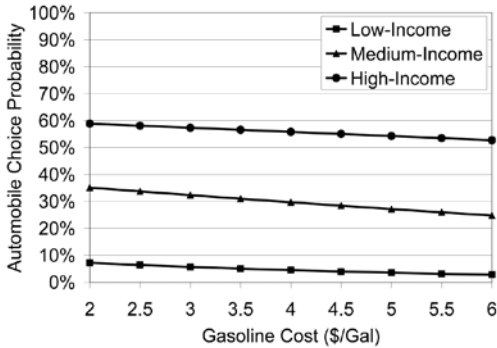
At \$6 per gallon, the gas price increase is 160, 200, and 267 cents per driving trip for the Low, Medium and High scenarios, respectively (due to differing assumed driving fuel economies). Figure 7(a) shows the equivalent fraction of gas-price “pass-through” for the different commuters in the Low scenario. It is near the maximum for all of the commuters, as few are able to switch to transit. In the Medium and High scenarios, since groups are less dependent on automobiles, the “pass-through” is reduced (Figures 7[b] and 7[c]). The low-income group, avoiding gas prices by taking transit, ends up seeing very little of the gas price increase in the scenario with better transit options.



(a)

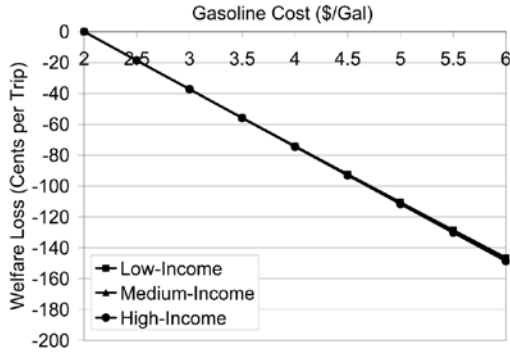


(b)

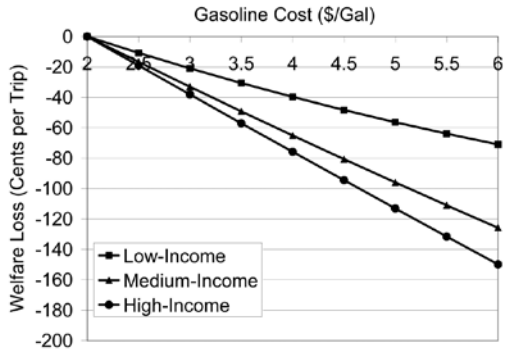


(c)

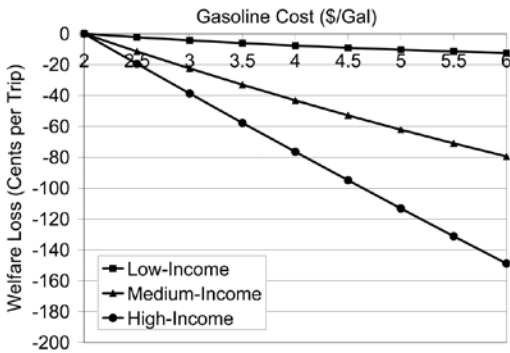
Figure 5. Automobile mode choice for the three income groups for the (a) Low, (b) Medium, and (c) High scenarios



(a)

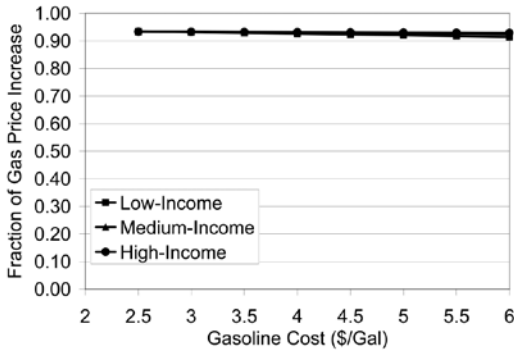


(b)

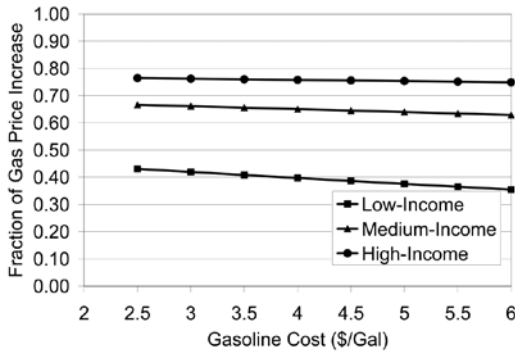


(c)

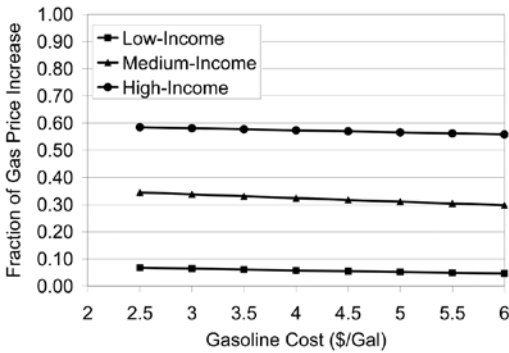
Figure 6. Welfare changes for the three income groups for the (a) Low, (b) Medium, and (c) High scenarios



(a)



(b)



(c)

Figure 7. Fraction of gas price increase “passed through” to commuters of different income levels for the (a) Low, (b) Medium, and (c) High scenarios

Impacts of Incremental Changes to the Low Scenario

While the scenarios represented systems where auto and transit levels of service differed greatly, the impacts of immediate policy changes to a particular corridor are also important. While no claim is made in this exploration to produce calculations needed to make policy recommendations or evaluations, a brief analysis of incremental changes to a scenario can point to some basic conclusions about the impact of transit service investments on welfare. Here, we took the Low transit scenario and reduced the expected access time from 25 minutes to 15 minutes and increased the average speed from 10 to 15 miles per hour. These are the kinds of outcomes expected from adding service frequency and operations improvements such as queue jumps, signal priority or limited-stop services. Automobile parameters (costs, levels of service) remain unchanged. Table 3 compares the welfare measures from the Low scenario to a scenario with these modifications at a gasoline price of \$6 per gallon. The incremental changes do show a significant effect on mode choice, welfare losses and pass through with losses falling by about five percent for all income groups.

Table 3. Comparing Outcomes of Low Scenario to Modified Low Scenario for a Gasoline Price of \$6

Scenario	Low			"Modified" Low		
	Low Income	Medium Income	High Income	Low Income	Medium Income	High Income
Automobile Mode Choice	89.0%	91.4%	92.4%	83.2%	86.7%	88.2%
Welfare Loss (Cents per Trip)	146.36	147.96	148.67	138.95	141.28	142.33
Gas Price Pass-Through (% of Gasoline Price Change)	91.5%	92.5%	92.9%	86.8%	88.3%	89.0%

Conclusions

This paper discusses, using a simple scenario model, what happens to per-trip costs under rising gas prices for travelers with different travel choice characteristics and incomes. Commuters with reasonable choices, where travel and access times for public transit were competitive with the automobiles, could avoid higher fuel prices by switching travel modes and incur smaller welfare losses than commuters in corridors where public transit options offer significantly lower levels of service. Commuters with poor choices were forced to pay the higher prices or switch modes and incur much longer trip times and welfare losses. These results

verify what one would expect to be the impacts of constrained choices under circumstances of rising prices and confirm the hypothesized conclusions laid out in the beginning of this paper.

In the “Low-Transit” scenario, nearly all of the low-income commuters were unwilling to switch modes to transit and incurred the same welfare losses as higher-income commuters. In effect, low-income commuters suffered more, as their loss as a share of their income is likely much higher than that for the high-income commuters. The High scenarios allowed low-income commuters an escape to avoid high gasoline prices while not incurring much longer travel times.

These scenarios illustrated significant impacts of travel choice on welfare under changing fuel prices. Further exploration of these issues is warranted, both for the concerns of low-income job access discussed earlier but also to understand how commuters in general can face likely future gas price increases without incurring large welfare losses from a lack of travel choices.

Acknowledgments

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Style versus Service?

An Analysis of User Perceptions of Transit Stops and Stations

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Abstract

Transit travelers expend a great deal of time and energy on out-of-vehicle walking and waiting, which significantly affects their perceived burdens of travel. Accordingly, this article is concerned with ways to reduce the perceived burdens of out-of-vehicle time spent walking, waiting, and transferring to improve users' experience at transit stops and stations. We surveyed 749 transit users at 12 transit stops and stations around metropolitan Los Angeles and found that the most important determinant of user satisfaction with a transit stop or station has little to do with the physical characteristics of the facility; instead, frequent, reliable service in an environment of personal safety matters most to riders. In other words, most transit users would prefer short, predictable waits for buses and trains in a safe, if simple or even dreary, environment over long waits for late-running vehicles in even the most elaborate and attractive transit station, especially if they fear for their safety.

Introduction

Travel by public transit involves much more than moving about on buses and trains. A typical door-to-door trip entails walking from one's origin to a bus stop or train station, waiting for the vehicle to arrive, boarding the vehicle, traveling in the vehicle, alighting from the vehicle, and then walking to one's final destination.

In many cases, the trip involves transfers; travelers alight from one transit vehicle, move to a new stop or platform, wait for another transit vehicle, and board that vehicle. Transit travelers expend a great deal of time and energy on this out-of-vehicle walking and waiting, which plays greatly into their perceived burden of transit travel. Despite the importance of out-of-vehicle transit travel, the in-vehicle travel experience has tended to garner the lion's share of attention from transit managers and researchers.

As cities have grown more dispersed and auto-oriented, the out-of-vehicle time share of transit trips has increased. In an effort to accommodate increasingly dispersed patterns of trip-making, many transit systems in U.S. metropolitan areas now require transit users to make frequent transfers among lines, modes, and operators. In metropolitan areas with large transit systems, transit stops and stations are integral parts of the transit network, playing an important role in connecting multiple transportation modes and systems. The effectiveness of these connections governs waiting and walking times at transit stops and stations, and, in turn, travelers' choices regarding whether or not to take a particular transit trip. Given the effect of travel time on travel choices, good connectivity at transit stops and stations is critical to overall transportation network effectiveness.

What are the best ways to reduce these out-of-vehicle travel burdens and improve transit users' experience at stops, stations, and transfer facilities? Are some approaches to improving the interconnectivity among transit lines, modes, and systems more cost-effective than others? Can out-of-vehicle travel improvements be made in a stand-alone fashion, or are they more effectively implemented in concert with other complementary actions? To address these questions, we devised a framework to relate transit stop and station attributes to travelers' out-of-vehicle burdens based on travel behavior research. Guided by this framework, we developed a methodology, which consists of Importance-Satisfaction analyses and ordered logistic regression models, to examine transit users' perceptions of services and the built environment at stops and stations. We applied this methodology to a survey of 749 transit users at stops and stations around metropolitan Los Angeles and identified the priorities that users place on means to improve their travel experience.

In sum, we found that transit users tend to care more about personal safety and frequent, reliable service than the physical conditions of transit stops and stations. In other words, given a choice between benches, shelters, and off-street stations,

or safe, frequent service, our findings suggest that most passengers will opt for the latter.

Previous Research and Conceptual Framework

The importance of waiting, walking, and transfer times to public transit riders has long been recognized in travel behavior research (Committee on Intermodal Transfer Facilities 1974). The literature on travel time valuation has clearly documented differences between in-vehicle travel time and out-of-vehicle travel time (Iseki and Taylor 2009).¹ In general, travelers perceive out-of-vehicle time (i.e., waiting, walking, and transfers) as more onerous than in-vehicle time. In his review and meta-analysis of British studies of transit travel times and service quality conducted between 1980 to 1996, Wardman (2001) reports that the average values of walking time, waiting time, and combined walking and waiting time relative to in-vehicle travel time were 1.66, 1.47, and 1.46, respectively. A few other studies, such as Wardman et al. (2001), Kim (1998), and the U.S. Environmental Protection Agency (2000), report the value of wait time and walk time relative to in-vehicle time ranges from 1.2 to 2.72, which varies by transit mode, trip purpose, and population size of the urban area, among other factors. Several modeling studies in the U.S. found slightly higher valuations of walking time, ranging from 2 to 4.5 times of in-vehicle time (Barton-Ashman Associates 1993; Parsons Brinckerhoff Quade and Douglas Inc. 1993, 1998, 1999).

Transit users' relative valuation of out-of-vehicle time depends on a wide array of external factors, such as quality of signage and information at transit facilities, vehicle arrival time uncertainty,² comfort, security and safety (which are, at least in part, influenced by service frequency), weather, and crime frequency (Moreau 1992; Hess, Brown, and Shoup 2005; MVA Consultancy 1987; Bruzelius 1979; Webster and Bly 1980; Reed 1995; Ryan 1996; Wardman 2001). Out-of-vehicle travel time valuation also has been found to be influenced by transit user characteristics, such as users' familiarity with the city, transit system, given line, and given stop, as well as the physical condition of the traveler, whether the traveler is late for work or an appointment, and whether the traveler can otherwise use the waiting time productively (Bronzaft, Dobrow, and O'Hanlon 1976; Reynolds and Hixson 1992; Woyciechowicz and Shliselberg 2005; Lacy and Bonsall 2001; Dziekan, Schlag, and Jünger 2004; Dziekan and Vermeulen 2006; Dziekan and Kottenhoff 2007; Dziekan 2008; Balcombe et al. 2004).

Because of the demonstrated importance of waiting, walking, and transferring (out-of-vehicle) times vis-à-vis in-vehicle travel times in the minds of travelers, improving travelers' out-of-vehicle (walk, wait, and transfer) transit experiences is important to making public transit more attractive to users. However, the research on how these observed out-of-vehicle travel burdens relate to the specific configurations of transit services, stops, and stations has received surprisingly little attention. And while many previous studies have investigated the physical attributes of transit stops and stations, this work has, in general, ignored much of the travel behavior research reviewed here and has lacked any conceptual logic linking stop/station improvements to increased ridership.

Why has there been so little careful research on the waiting, walking, and transferring experience of travelers? First, as noted above, both practitioners and researchers have tended to pay more attention to the quantity and quality of in-vehicle travel, probably because transit managers have more control over what happens on buses and trains than at stops and stations, which often are controlled by other entities. Second, because transfer facilities vary in size, modes served, location, and amenities, it is a challenge to comprehensively analyze transfer facilities using uniform criteria (ITE Technical Council Committee 5C-1A 1992). Third, most previous studies of transit stops and stations typically have compiled laundry lists of positive and negative attributes, but have largely failed to consider their relative importance or whether they influence ridership differently alone or in concert with other factors (Rabinowitz et al. 1989; Fruin 1985; Kittelson & Associates 2003; Vuchic and Kikuchi 1974; Evans 2004). Most of these previous studies have been conducted from what could be best described as a design perspective, suggesting rather obvious improvements (providing more seats and shelters, improving lighting, keeping facilities clean, etc.), although research has clearly shown that the factors influencing valuation of out-of-vehicle time are not limited to certain built environment and amenities of bus stops and rail stations. Few studies, however, have measured the effects of various stop attributes on people's travel behavior. This lack of causal clarity makes it difficult for transit planners and managers to determine how to lessen the burdens of waiting, walking, and transferring at transit stops cost-effectively (Liu, Pendyala, and Polzin 1997). As a result, we know little about which attributes of transfer facilities are most important, under which circumstances, and in which combinations.

To address the shortcomings in much of the previous research on transit stops and stations, we drew on the transfer penalty work of Liu, Pendyala, and Polzin

(1997), Wardman (2001), and Guo and Wilson (2004) to develop a wait/walk/transfer impedance framework to systematically evaluate the attributes of the out-of-vehicle transit travel experience (Iseki and Taylor 2009). The concept of transfer penalty represents generalized costs—including monetary costs, time, labor, discomfort, inconvenience, etc.—involved in transferring from one vehicle to another of the same mode (e.g., bus to bus) or a different mode (e.g., bus to train, walking to bus, etc.), and is well-established theory in the travel behavior literature (Rabinowitz et al. 1989; Fruin 1985; Kittelson & Associates 2003; Vuchic and Kikuchi 1974; Evans 2004; Iseki and Taylor 2009). While we intend, in a subsequent phase of this research, to relate reported user perceptions to both the physical characteristics and service frequencies at stops or stations, in this article we focus on the relative importance that users place on various aspects of their wait/walk/transfer experience at particular transit stops and stations, and their levels of satisfaction with each of these aspects.

Research Method

Drawing on the literature and our conceptual framework, we designed a survey of 46 self-administered questions to collect data from passengers on their perceptions of each of five categories of transit stop and station attributes: 1) access, 2) connection and reliability, 3) information, 4) amenities, and 5) security and safety (Iseki and Taylor 2009). Specifically, we asked transit passengers (in both English and Spanish) to assess the level of importance of multiple service features and their level of satisfaction at the stop or station where the survey was being administered under the current conditions on a four-point scale from “very important” to “not important” and “strongly agree” to “strongly disagree.” We used survey participants’ responses in the Importance-Satisfaction (I-S) analysis to identify which attributes passengers found most important and which (based on their collective in-the-moment perceptions at a wide array of transit stops and stations) tended to need the most improvement. We then employed ordered logistic regression analyses to determine the relative importance of the five-category attributes to users’ collective satisfaction with the transit facility at the time of their transfer. The survey also contained 12 questions about passenger demographics and trip characteristics, such as race/ethnicity, gender, household income, trip purpose, available mode alternatives, and station accessibility.

We carefully selected a dozen transit stops and stations in metropolitan Los Angeles to reflect the enormously wide variety of such facilities (Figure 1). Despite

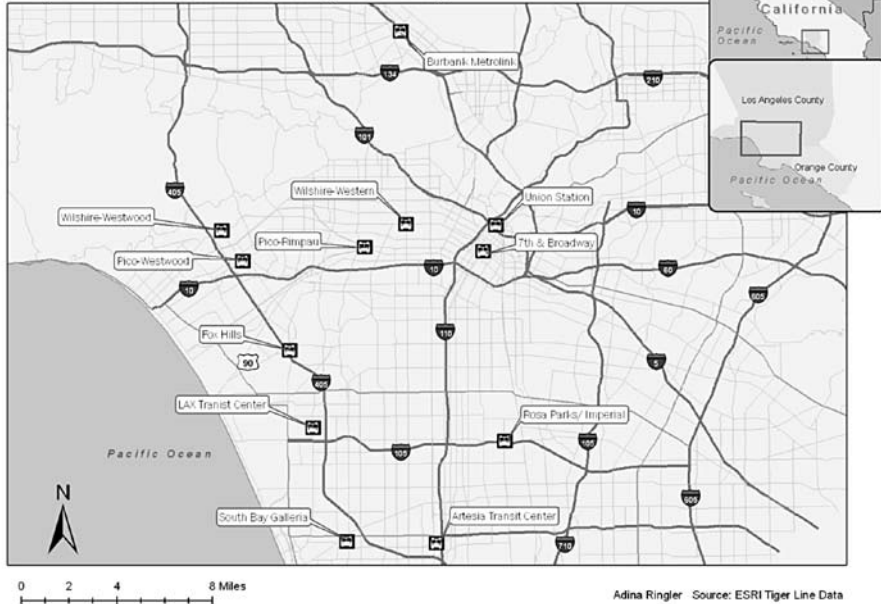
its image as perhaps the most sprawling, car-oriented American metropolis, Los Angeles is neither. To the surprise of many, Los Angeles is the nation's most densely populated urbanized area. It has fewer lane-miles of streets and roads per capita than all but Honolulu. In addition, while the residents of a dozen urbanized areas, on average, drive fewer miles per day than Angelinos, the residents of the remaining 452 urbanized areas drive more (U.S. Federal Highway Administration 2008). Overall transit use (measured in terms of unlinked trips) in Los Angeles ranks second nationally to New York, while transit use per capita ranks 10th—behind New York, San Francisco-Oakland, Washington, Boston, Chicago, Philadelphia, Portland, Baltimore, and Seattle.³ The stops and stations selected ranged from a simple bus stop signpost on a crowded, dirty street corner to the striking Union Station/ Gateway Center complex with its six modes of transit service and mission-style leather chairs in the waiting areas. Our aim was to survey a wide array of transit users at a wide array of transit stops and stations to reflect, as much as possible, the diverse experiences of transit users generally.⁴

We then classified the stops and stations into five categories, from simple local bus stops to major intermodal transfer facilities, based on quantitative and qualitative evaluations of the 1) volume of passengers and activities, 2) number of interfacing routes, 3) number of interfacing modes, 4) physical configuration, 5) extent and quality of amenities, 6) transit center scope (community, regional, or other), and 7) presence of commercial joint developments (Fruin 1985).

Passengers were surveyed at different times of the day on different days of the week between December 2006 and March 2007. We approached 1,023 passengers, and a total of 749 riders participated (73% response rate). Most declinations occurred because the person was leaving the stop or station or because the bus or train was due shortly. In addition, it should be noted that not all of the 749 surveys were fully completed, as many survey participants had to stop taking the survey in order to catch their bus or train.

Intermodal Transfer Facilities

Surveyed transfer facilities in Los Angeles County



Station Name	Station Type	Level
L.A. Union Station	Bus-Heavy Rail- Light Rail- Commuter Rail	5: A major grade-separated, multi-modal, multi-level bus or rail-transfer facility.
Wilshire/Western (Purple HRT x Metro Rapid)	Bus-Heavy Rail	4: An urban grade-separated multi-modal transit facility with exclusive bus access provisions and elevated or subway rail access.
Imperial/Wilmington (Blue x Green LRT)	Bus-Light Rail	
Galleria at South Bay Transit Center	Bus	3: An off-street facility, serving multiple routes, and possibly multiple modes
LAX Bus Center	Bus	
Fox Hills Transit Center	Bus	
Pico/Rimpau Transit Center	Bus	
Artesia Transportation Center	Bus	
Burbank Metrolink Station	Bus-Commuter Rail	
Pico & Westwood	Bus	1: A local stop serving a single transit mode
Wilshire & Westwood	Bus	
Broadway & 7th (Metro Center)	Bus	

Note: Level 2 is a slightly upgraded form of facility—for example, an on-street bus turnout with loading bays separated from regular traffic lanes and raised platform rail station.

Figure 1. Location of surveyed transit stops and stations in Los Angeles County

Analysis of Survey Data

In the sections following, we present findings from the I-S analysis and ordered logistic regression analysis of transit users' perceptions of transit services and facilities, measuring attributes on the basis of both user satisfaction and importance to users. We confirmed that transit users' demographics and trip characteristics in our survey were comparable to those reported by the Los Angeles County Metropolitan Transportation Authority in 2002 (LACMTA 2002); the only exceptions were that the household incomes and the proportion of white riders were higher among our respondents. This is almost certainly because our surveys included more riders of suburban and commuter services operated by transit systems other than the central-city focused LACMTA.

Importance-Satisfaction Analysis

I-S analysis can help transportation planners and managers evaluate the relative priority they should place on various options (Tennessee Department of Transportation Office of Strategic Planning 2006). I-S analysis helps transit managers maximize the impact of new investments on customer satisfaction by focusing improvements in areas where customer satisfaction is low and importance to customers is high (Tennessee Department of Transportation Office of Strategic Planning 2006). Thus, using indices of improvement need (I-S rankings), transit agencies can direct investments toward improvements that will be most beneficial to their customers.

To obtain an attribute's importance rating, we calculated the proportion of respondents who ranked it "very important" out of the total number of valid answers in the survey. To obtain the satisfaction rating, we calculated the proportion of survey respondents who indicated satisfaction with the attribute ("strongly agree" or "agree somewhat"). These ratings are expressed in percentages. Based on the ratings of 16 attributes (excluding riders' reported overall satisfaction level), we determined rankings for both importance and satisfaction.

Then, the I-S rating was computed for each attribute by multiplying the importance rating by 1 minus the satisfaction rating.

$$\begin{aligned} IS &= [Importance \times (1-Satisfaction)] \\ &= [Importance \times Dissatisfaction] \end{aligned} \quad (Eq-1)$$

The maximum rating of 1.00 occurred when all respondents considered an attribute "very important," but no respondents were satisfied with the current quality

of the attribute. The minimum rating of 0.00 occurred when one of the following was true:

1. No respondents considered the attribute “very important,” and/or
2. All respondents were at least somewhat satisfied with the current quality of the attribute (i.e., all respondents chose “strongly agree” or “agree somewhat” with a satisfaction statement in the survey).

The I-S rating is thus an index that assesses the need for improvement; the higher the I-S rating, the greater the improvement need. Ideally, an agency could prioritize stop/station improvement planning based on I-S ratings, though in this study the results are aggregated across a dozen facilities to produce more general and generalizable levels of importance and satisfaction with the transfer experience at a heterogeneous set of surveyed transit facilities. If these data and I-S ratings were used for planning purposes, the data reported here would need to be disaggregated by facility.

Rating and Ranking of Importance, Satisfaction Level, and Importance-Satisfaction

After calculating I-S ratings for each of the attributes across the dozen facilities surveyed, we ranked each attribute from 1st to 16th. Table 1 shows 1) the proportion of respondents who placed the highest level of importance on each factor in the survey (“Rate”) and rankings (“Rank”) from 1st to 16th for each of the criteria (with a rank of “1” indicating greatest important and highest satisfaction), 2) the proportion of respondents who placed the highest and second highest levels of satisfaction (“strongly agree” or “agree somewhat”) on each issue, and 3) the I-S rating, which combines 1) and 2) in the “I-S” columns (codes in Table 1 are used in Figure 1). To enable comparisons across general attribute categories, the unweighted means of importance ratings, satisfaction ratings, and I-S ratings and rankings for each category are also shown in the shaded rows in Table 1.

Table 1 shows that “safety at night” received the highest importance ranking (78%), followed closely by the “safety during the day” (77%). This indicates that, overall, passengers felt that safety and security are the most important factors in determining their stop/station experience. The third most important stop/station attribute (though very nearly equal to the first two safety factors) was schedule adherence (76%), which in this analysis was categorized under Connection & Reliability. So, while two safety and security (SS1 & SS2) questions were ranked by

Table 1. Rating and Ranking for Importance, Satisfaction, and Importance-Satisfaction

Question on the Survey	Category	Code	Importance		Satisfaction		IS	
			Rate	Rank	Rate	Rank	Rate	Rank
This station/stop area is clean.	Amenities	A1	58%	13	78%	6	13.1%	13
There are enough places to sit.		A2	50%	15	65%	12	17.5%	9
There are places for me to buy food or drinks nearby.		A3	34%	16	57%	14	14.8%	10
There is a public restroom nearby.		A4	59%	12	40%	16	35.5%	1
There is shelter here to protect me from the sun or rain.		A5	69%	8	69%	8	21.2%	7
Average		A	<u>54.1%</u>	<u>12.8</u>	<u>61.7%</u>	<u>11.2</u>	<u>20.4%</u>	<u>8.2</u>
The signs here are helpful.	Information	I1	69%	9	81%	4	13.3%	12
It is easy to get schedule and route information at this station.		I2	62%	11	66%	11	21.4%	6
Average		I	<u>65.6%</u>	<u>10.0</u>	<u>73.2%</u>	<u>7.5</u>	<u>17.3%</u>	<u>9.0</u>
I usually have a short wait to catch my bus/train.	Connection & Reliability	CR1	70%	6	66%	9	23.7%	5
My bus/train is usually on time.		CR2	76%	3	67%	10	25.0%	4
Average		CR	<u>72.8%</u>	<u>4.5</u>	<u>66.6%</u>	<u>9.5</u>	<u>24.3%</u>	<u>4.5</u>
It is easy to get around this station/stop.	Access	AC1	57%	14	89%	1	6.2%	16
It's easy to find my stop or platform.		AC2	70%	7	89%	2	7.6%	15
Average		AC	<u>63.6%</u>	<u>10.5</u>	<u>89.1%</u>	<u>1.5</u>	<u>6.9%</u>	<u>15.5</u>
I feel safe here during the day.	Security & Safety	SS1	77%	2	85%	3	11.3%	14
I feel safe here at night.		SS2	78%	1	57%	13	33.1%	3
There is a way for me to get help in an emergency.		SS3	74%	4	55%	15	33.7%	2
This station is well lit at night.		SS4	73%	5	74%	7	18.9%	8
Having security guards here makes me feel safer.		SS5	67%	10	79%	5	13.9%	11
Average		SS	<u>73.8%</u>	<u>4.4</u>	<u>70.1%</u>	<u>8.6</u>	<u>20.4%</u>	<u>7.4</u>
This is an easy place to transfer to another bus or train.	Over-all	-	73.1%	-	88.3%	-	8.6%	-

Note: A low Importance Rank value indicates that users deem an attribute highly important. A low Satisfaction Rank value indicates that users highly satisfied with an attribute. Low IS-ratings represent the greatest need for improvement.

respondents as most important, the two questions on Connection & Reliability (CR1 & CR2) ranked just below Safety, also rated as relatively important by users.

The “satisfaction” columns in Table 1 show the ratings and rankings for riders’ satisfaction with each attribute at the heterogeneous set of stops and stations where surveys were conducted. Most respondents (88%) are at least somewhat satisfied with the overall quality stops where they were surveyed. Among the five categories examined, Access received the highest average satisfaction rating (89%). Respondents also were generally satisfied with the ease of navigating to, from, and within the facilities. Within the Information category, signs received a very high satisfaction rating (81%), while riders rated availability of schedule and route information lower (66%). The Connection & Reliability category received a low average rating overall, indicating that passengers were relatively dissatisfied with schedule adherence and wait times.

Table 1 shows that individual stop/station attribute ratings varied significantly within the Amenities and Security & Safety categories. In the Security & Safety category, in particular, there was a large gap in the level of satisfaction between daytime and nighttime safety. Most respondents were satisfied with the level of safety during the day (85%), but 43 percent did not feel safe at night.

Based on the I-S rating, the availability of a public restroom (35.5%), an emergency contact method (33.7%), and safety at night (33.1%) were, in the views of respondents, the three things most in need of improvements across all of the transit stops and stations surveyed. The high I-S ranking for restrooms indicates that passengers felt strongly that more (and better)⁵ public restrooms should be provided at transit stops and stations. For those who were transferring at their stop or station, an emergency communication device (such as a panic button at stops) and general safety at night were especially strong concerns.

Riders assigned high priority to two items in the Connection & Reliability category: schedule adherence (25%) and wait time (23.7%). The reliability of transit service is very important to riders, yet, other than personal experience, most riders have no access to either real-time or historical information about a particular line’s schedule adherence—though this is slowly changing with growth of real-time “next bus/train” information at stops/stations. These results suggest that either providing such real-time information or improving published schedule adherence could substantially reduce the perceived burdens of transit travel.

Figure 2 shows the importance ratings on the X-axis and the satisfaction ratings on the Y-axis (the letter/digit codes in this figure relate to those presented in the 3rd column of Table 1). This figure visually summarizes the relationship between the relative importance and level of satisfaction these 749 transit users attribute to each service feature at the dozen stops and stations surveyed. By plotting the importance and satisfaction ratings of each attribute relative to the means, transfer facility attributes can be classified into four categories.

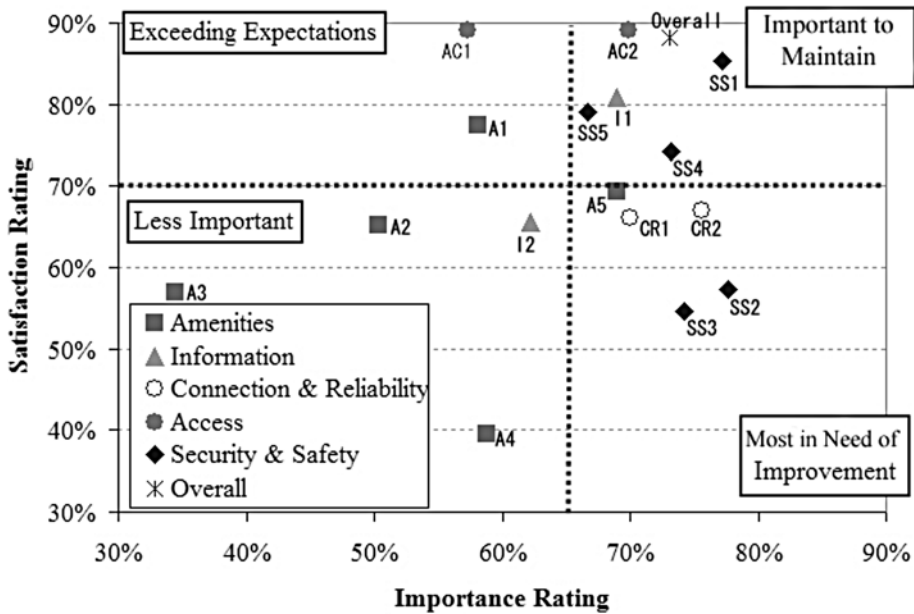


Figure 2. Four categories of importance and satisfaction levels

Attributes that fall in the bottom-right quadrant (“Most in Need of Improvement”) require immediate attention due to low average satisfaction combined with high average importance ratings. These attributes include availability of emergency communication devices (SS3), overall safety at night (SS2), availability of public restrooms (A5), schedule adherence (CR1), and average wait time (CR2).

The top-right quadrant of Figure 2, labeled “Important to Maintain” depicts attributes that surveyed users have rated “very important” and with which they are relatively satisfied. Such responses suggest that entities overseeing these stops and stations are doing a relatively good job on factors that are very important to users. The attributes in this category fall under Safety & Security, Access, and Informa-

tion and include station lighting (SS4), presence of security guards (SS5), general safety during the day (SS1), ease of accessing schedule and route information (I1), and ease of locating the stop or platform (AC2).

Two attributes received very high satisfaction ratings, but below-average importance ratings (labeled “Exceeding Expectations” in the top-left quadrant). In the Access category, passengers were most satisfied with the ease of navigating around the station or stop (AC1) and, in the Amenities category, passengers were satisfied with the cleanliness of the facility (A1). These results suggest that the surveyed transit facilities are meeting users’ expectations for these attributes.

The last group of attributes (“Less Important” in the bottom-left box) received low user satisfaction and importance ratings. These attributes were (somewhat surprisingly to us) seating (A2), places to buy food or drink (A3), shelter from the rain or sun (A4, perhaps reflecting the mild Southern California climate), and the helpfulness of the signs at the station/stop (I2).

The I-S ratings by category suggest that Connection & Reliability at the dozen Los Angeles transit stops and stations surveyed require the most improvement relative to the four other categories. We can thus expect that improvement of on-time performance and implementation of timed transfers would likely significantly affect user satisfaction. Although Safety & Security received the highest importance ranking, it received a moderate satisfaction rating for the stops and stations surveyed, which yielded the second highest I-S rating. Safety & Security was the most important factor in determining whether travelers choose to use transit, and it can increase perceived costs related to waiting infinitely; that is, if travelers feel a waiting/transfer location is profoundly unsafe, most will forego using public transit entirely (ITE Technical Council Committee 5C-1A 1992). In this sense, respondents in this survey, who are already traveling by transit, may exhibit a higher Safety & Security satisfaction level than the general population.

Relative Importance of Transfer Facility Attributes based on Satisfaction Ratings

One of the central questions motivating this research is which transit stop and station attributes most influence traveler’s decisions to use public transit. The more satisfied transit users are with their waiting, walking, and transferring experiences, the more likely they are to take transit. In order to examine relative importance of transit stop and station attributes, we conducted chi-square tests and ordered logistic regression analyses, using the various satisfaction ratings described above.⁶

In our survey, the dependent variable had four ordinal categories: strongly agree, agree, disagree, and strongly disagree.

We then employed chi-square tests to confirm that all of the responses to the 16 questions about individual stop/station attributes do indeed influence the distribution of responses to the question about users' overall satisfaction with the stop or station. As expected, we found that responses to each of the questions about individual attributes did influence the users' overall satisfaction with the stop/station where the survey was conducted in a statistically significant sense.

Because chi-square tests do not indicate the ordered effect of each of the attribute responses on overall stop/station satisfaction levels, we performed a series of simple ordered logistic regression analyses relating each of the 16 independent variables from the survey to the overall satisfaction question. Since each of the explanatory variables are ordinal, we used three dummy (or dichotomous [0, 1]) variables to differentiate among the four levels of responses. Pseudo- R^2 , which is similar to R^2 in Ordinary Least Regression (OLS), is an indicator of the goodness of fit; it was used to examine the relative performance of each factor in explaining passengers' overall satisfaction with a stop or station. The pseudo- R^2 s of the single ordered logistic regression analyses collectively show that overall ease of navigation at the transfer center, personal safety, and service reliability are the most important contributors to a passenger's overall satisfaction with a stop or station. Specifically:

1. "It's easy to get around this station/stop" (pseudo- $R^2 = 0.16$, significant at 3 response levels)⁷ is most important overall.
2. "I usually have a short wait to catch my bus/train" (pseudo- $R^2 = 0.12$, significant at 3 response levels) is second.
3. "It's easy to find my stop or platform" (pseudo- $R^2 = 0.12$, significant at 1 response level) is third.
4. "This station is well lit at night" (pseudo- $R^2 = 0.11$, significant at 2 response levels) is fourth.
5. "Having security guards here makes me feel safer" (pseudo- $R^2 = 0.10$, significant at 1 response level) is fifth.

In contrast, station amenities and cleanliness (public restrooms, food/drink sales, places to sit, shelter from sun/rain, and cleanliness) were least important in explaining respondents' overall satisfaction.⁸

In addition to the single ordered logistic regression analysis, we conducted a multivariate ordered logistic regression analysis to examine the simultaneous effects of the 16 independent user perception variables on reported overall levels of stop/station satisfaction for 512 valid observations. After numerous iterations in which we sought to identify a set of statistically significant independent variables while taking into account the sometimes high levels of collinearity among them, we obtained the results shown in Table 2, which presents our final model. The independent variables in this model are listed in order of the scale of their effects (coefficients). The pseudo R^2 in this model indicates that approximately 27 percent of the variance in the level of user stop/station satisfaction is explained by the variance of the seven independent variables included in the final model. The first and second columns show the level of response (3–agree and 4–strongly agree as opposed to the two other responses, disagree and strongly disagree, combined as the base) and a stop/station attribute. For example, “CR2-4” and “My bus/train is usually on time” indicate that a dummy variable was used to measure users’ “strong agreement” with the satisfaction of on-time performance. The columns labeled “z” and “ $P > |z|$ ” indicate that all variables included in this parsimonious final model are statistically significant at the 95% confidence level.

Since all variables in the model are dichotomous dummy variables used to indicate whether the users’ overall stop/station satisfaction level is something other than “strongly disagree,” we can compare coefficients among variables directly. However, as this is not a linear regression model, the effects of coefficients reported in Table 2 to determine the overall satisfaction level are not linear as in the OLS. Instead, the effects should be interpreted as the probability that a given factor will effect a change in each overall satisfaction level (Table 3).

The penultimate row in Table 2 shows the cut point (or threshold value) separating those who disagree or strongly disagree with a statement that they are satisfied overall with the transit stop or station (in other words, that they are unsatisfied or very unsatisfied with the stop or station overall), and those who agree with the statement that they are satisfied with the stop or station. Likewise, the last row shows the cut point between those who are satisfied with the stop or station, and those who are very satisfied.⁹ It should be noted that we obtained similar results from the statements “I feel safe here at night” (SS2) and “I feel safe here during the day” (SS1). Due to the high correlation between these two variables, however, we included just one (SS1: “I feel safe here during the day”) of these two variables in the final model.

Table 2. Final Ordered Logistic Regression Model of Factors Predicting Users Overall Satisfaction Level with their Transit Stop or Station

Number of observations: 512		Prob > chi2 = 0.0000			
LR chi2(8) = 255.37		Pseudo R2 = 0.2674			
Log likelihood = -349.8149					
Survey Questions	Category	Coef.	Std. Err.	z	P> z
CR2-4 My bus / train is usually on time.	Connection & Reliability	1.270	0.397	3.20	0.00
SS5-4 Having security guards here makes me feel safer.	Security & Safety	1.244	0.228	5.45	0.00
SS4-4 This station is well lit at night.	Security & Safety	1.102	0.330	3.34	0.00
SS1-4 I feel safe here during the day.	Security & Safety	1.049	0.310	3.39	0.00
SS1-3	Security & Safety	0.961	0.265	3.63	0.00
AC1-4 It is easy to get around this station / stop.	Access	0.934	0.282	3.31	0.00
I1-4 The signs here are helpful.	Information	0.555	0.262	2.12	0.03
AC2-4 It's easy to find my stop or platform.	Access	0.516	0.256	2.02	0.04
Cut point between "strongly disagree and disagree" & "agree"		-0.175	0.235		(Ancillary
Cut point between "agree" and "strongly agree"		2.262	0.265		parameters)

Table 3. Probability of the Overall Satisfaction Level for Transfer Facilities

Survey Questions	Category	Response	Mean Probability of Responses	
			#	Agree Strongly Agree
CR2 My bus / train is usually on time.	Connection & Reliability	* Strongly Agree	0.11 0.03	0.48 0.25
SS5 Having security guards here makes me feel safer.	Security & Safety	* Strongly Agree	0.13 0.04	0.50 0.29
SS4 This station is well lit at night.	Security & Safety	* Strongly Agree	0.11 0.04	0.48 0.28
SS1 I feel safe here during the day.	Security & Safety	# Agree Strongly Agree	0.16 0.07 0.06	0.52 0.38 0.36
AC1 It is easy to get around this station / stop.	Access	* Strongly Agree	0.12 0.05	0.49 0.33
I1 The signs here are helpful.	Information	* Strongly Agree	0.11 0.07	0.47 0.39
AC2 It's easy to find my stop or platform.	Access	* Strongly Agree	0.11 0.06	0.47 0.38

*: Strongly disagree, disagree, and agree combined; #: Strongly disagree and disagree combined.

This multivariate ordered logistic regression analysis considers the influence of each of many stop or station attributes while controlling, to the extent possible, for the independent influence of other attributes. Thus, the scale of coefficients in Table 2 indicates the relative importance of the explanatory variables examined. Significantly, the most important factor in determining respondents' overall satisfaction with a transit stop or station has nothing to do with the stop or station itself—it is the on-time performance of the transit service. This is an important finding, though it should come as no surprise to anyone familiar with travel behavior research. Put another way, the perceived burden of waiting for or transferring between transit vehicles is reduced substantially by reliable and frequent service. This finding is all the more reliable because the respondents to this survey were aware that the foci of our analysis were transit stops and stations, and not transit service in general.

Following schedule adherence, the next three most important stop or station attributes, according to those surveyed for this study, concern personal safety (security guards, lighting, and overall perceptions of security). The three factors after that related to the navigability of the stop or station (easy to get around, signs are helpful, easy to find stop or platform).

To see how a response to the quality of each attribute influences the overall satisfaction level for the facility, probabilities of a given overall stop/station satisfaction level were calculated from the estimated coefficients in Table 2 using the mean values for all variables in the regression model. Table 3 shows that the satisfaction level with each of the final model's attributes clearly influences the users' overall satisfaction level with the transit stop or station. For example, when a transit user is strongly satisfied with on-time performance (CR2), the probability that this person is strongly satisfied with the overall quality of the transit facility increases from 0.41 to 0.71. This same interpretation applies to all of the variables listed.

Overall, the results of this ordered logistic regression are consistent with our findings from the I-S analysis. Connection and reliability factors are the most important, followed by security and safety factors. A few attributes in the Access and Information categories also significantly influence users' satisfaction levels, but amenities in general are not nearly as important as the other attributes tested.

Concluding Remarks

In this article, we sought to address the general lack of causal clarity that plagues much previous research on transit stops and stations. We examined 749 transit users' perceptions of the quality of service and built environment at 12 transit stops and stations around metropolitan Los Angeles, employing an Importance-Satisfaction analysis, chi-square tests, and ordered logistic regression analyses to examine which stop and station attributes matter most to transit users' experience.

The principal finding of this analysis is clear: the most important determinant of user satisfaction with his/her transit stop or station had little to do with physical characteristics of that stop or station—it is frequent, reliable service in an environment of personal safety. While this study was confined to 749 transit users surveyed at all times of the day and week at 12 very different transit stops in one very large metropolitan area, we believe that both the size and heterogeneity of the sample permit us to generalize somewhat from these findings. To wit, most transit users would prefer short, predictable waits for buses and trains in a safe, if simple or even dreary, environment, over long waits for late-running vehicles in even the most elaborate and attractive transit facility, especially if they fear for their safety. While this finding will come as no surprise to those familiar with past research on the perceptions of transit users, it does present a rather dramatic contrast to much of the descriptive, design-focused research on transit transfer facilities (Rabinowitz et al. 1989; Project for Public Spaces 1999; Texas Transportation Institute, Texas A&M Research Foundation, and Texas A&M University 1996), and to public transit finance policies and programs that strongly emphasize capital expenditures over operating.

Of our 16 stop and station attributes evaluated, transit users assigned the highest importance to factors related to security and safety, and then to factors related to connection and reliability. In contrast, stop and station-area amenities were ranked as least important by users. Respondents' level of satisfaction with each attribute under the current conditions at the 12 survey sites in the Los Angeles metropolitan area indicates that users are least happy with factors related to access, followed by some factors related to security and safety and connection and reliability. The I-S rating, which combines users' perception of the importance of and satisfaction with various aspects of the waits/walk/transfer experience at individual transit facilities, indicates that factors most in need of improvement tend to pertain to security and safety and connection and reliability and least to amenities. This is not to say that physical amenities are not important to travelers

—more than half ranked information, public restroom availability, cleanliness, and ease of navigation as important. Rather, travelers prefer safe, frequent, reliable service over such factors.

We also employed the ordered logistic regression model to measure the influence of each of the 16 stop/station attributes on users' overall satisfaction with their wait/walk/transfer experience at each transit facility, while simultaneously controlling for the effects of all other measured "satisfaction" attributes. This type of analysis tends to eliminate all but one of closely-related factors (such as "I feel safe here at night" and "This stop/station is well-lit at night") while elevating ostensibly less-important factors that independently influence users' overall levels of satisfaction. This analysis indicates that the most important factor affecting transit users' overall stop/station satisfaction is on-time performance, followed by presence of a security guard for safety, adequate lighting, adequate safety during the day, ease of getting around a facility, and good signage.

These findings should be heartening to transit managers focused on delivering quality transit service to users. A relatively large body of research suggests that transit subsidy programs, particularly the federal programs, strongly favor capital expenditures on facilities and vehicles over operating expenditures on service (Pickrell 1986; Wachs 1989; Li and Taylor 1998; Taylor and Samples 2002). While the reasons behind this capital bias are many, they collectively encourage a focus on the physical characteristics of transit vehicles, stops, and stations over improvements to service frequency or reliability. While comfortable, informative, and attractive stops and stations can make traveling by public transit more agreeable, what passengers really want most—at least in this sample—is safe, frequent, and reliable service, plain and simple.

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Endnotes

¹ We extensively review the literature on valuation of out-of-vehicle travel time—waiting time, walking time, transferring time, and non-time-specific transfer penalties—vis-à-vis in-vehicle time in (Iseki and Taylor 2009).

² Travel time uncertainty is likely perceived as a significant burden by most travelers. Atkins and Polak (1997) show that the relative weight values of mean and one-standard deviation of wait times are 2.6 and 2.5, respectively, which suggests that reducing arrival time uncertainty (or increase in waiting time reliability) has about the same effect on generalized costs of transit trip as a corresponding reduction in headways.

³ Authors' calculations from U.S. Federal Highway Administration, 2006, Table HM-72, and American Public Transit Association at <http://www.apta.com/research/stats/ridership/uzapmiles.cfm>.

⁴ A detailed analysis of the responses to this survey is available from the authors.

⁵ A relatively high share (43%) of the stops and stations in this sample actually had a restroom available, while 57 percent of respondents were surveyed stops/stations with no public restrooms nearby—the latter characterizing the situation at most transit stops nationwide. While 71 percent of respondents at no-restroom stops/station were unsurprisingly very or somewhat dissatisfied with the availability of restrooms, 46 percent of respondents at with-restrooms stops were similarly dissatisfied. This speaks, perhaps, to the quality of the public restroom experience at transit stops and stations—that they tend to be better in theory than practice.

⁶ The chi-square test is a method used to examine whether the distribution of observations among categories of a dependent variable is influenced by another categorical variable (Fox 1997; StataCorp LP 2005). Ordered logistic regression is a method used to examine the relationships between a series of independent variables and an ordinal dependent variable. As in other logistic regression models, the dependent variable is not continuous, but categorical. In ordered logistic regression, the particular order of values in the dependent variable is important, while differences between two consecutive values of a dependent variable are not. More details on the use of ordered logistic regression model can be found in STATA manuals (2005) and other advanced statistics textbooks.

⁷ "Response level" refers to a user response of 1–strongly disagree, 2–disagree, 3–agree, and 4–strongly agree to a statement that the user is satisfied with each stop or station attribute.

⁸ While our findings here regarding restrooms would appear to contradict our earlier findings from the IS analysis that transit users consider stop/station area restrooms important and are largely unsatisfied with them, the findings are in fact consistent.

⁹ Cut point values are used to compute probabilities that each observation with certain independent variable values fall within each category of a dependent variable, taking into account the disturbance factor, which is assumed to be logistically distributed (StataCorp LP 2005). For example, when all independent values of the obtained regression model are zero, then probabilities for each of three categories (1&2, 3, and 4) are 0.456, 0.449, and 0.094, respectively.

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Federally-Mandated Evaluation of New Starts Transit Projects

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Abstract

Over the last 20 years, numerous metropolitan regions in the U.S. have implemented new, and upgraded existing, rail and bus rapid transit (BRT) fixed guideway systems funded by the federal "New Starts" program. Now, one condition of receipt of federal New Starts funds is that the project sponsor conduct an evaluation, called a Before and After Study, to determine the cost and ridership impacts of the transit project. Upon completion of this study, it must be submitted to the Federal Transit Administration (FTA) of the U.S. Department of Transportation, which is mandated to summarize these reports and submit them as an annual New Starts Before and After Studies Report to Congress. Based on a review of the annual New Starts reports that have been conducted to date, this paper describes the key findings of these Before and After Studies and analyzes their implications for mandated program evaluation research in the transit field.

Background

Over the past 20 years, there has been a tremendous growth in interest by U.S. metropolitan regions in building new or expanding existing public transit systems. While most of the attention by local planners and policymakers has been on light rail projects, other fixed guideway systems have been built or expanded, including heavy rail subways and BRT busways. The federal program that partially funds fixed guideway transit projects is called New Starts and, as of 2003, 25 projects

had received New Starts Full Funding Grant Agreements (FFGA) from FTA. Furthermore, 52 other transit providers were in some stage of New Starts planning and development and 151 potential New Starts projects were identified in the 2003 National Transportation Act (Dittmar 2004). Transit fared very well under the current national transportation law (called SAFETEA-LU) by authorizing \$45 billion in guaranteed funding over six years (an increase of 16%). The reasons for this “boom” in transit investments are multiple, but “critics have charged that America’s new rail projects have nothing to do with economics and everything to do with politics: city boosterism; and political monument building” (Cervero 1998, p. 440).

In an effort to balance the political influences in transit decision making with a data-driven, long-term investment perspective, federal officials and policymakers have called for expanding evaluation efforts associated with New Starts projects (Fisher 2003). In response to this demand for greater effectiveness and transparency, in 2001 the U.S. Congress mandated that Before and After Studies be conducted for all New Starts projects and that FTA report annually to Congress on the major findings of these studies. This paper describes the characteristics of the Before and After Study mandate, the findings of the Before and After Studies that have been implemented to date, and analyzes the implications for evaluation research in the transit field.

The Evolution of Federal Evaluation Mandates

Beginning in the 1960s, program evaluation has grown as a professional field and has been institutionalized through the use of federal evaluation mandates. Programs such as the War on Poverty, Medicare, Medicaid, and the Elementary and Secondary Education Act incorporated some form of systematic program evaluation and led to a tenfold increase in federal funding for evaluation by the 1970s (Carman 2008). Originally, these mandates focused on evaluating the effectiveness of individual programs in achieving their goals, but by the late 1960s, they were broadened to include performance-based management and budgeting. For example, the Planning, Programming and Budgeting Systems (PPBS) of the Johnson Administration, the Management by Objectives (MBO) approach of the Nixon Administration, and Zero Based Budgeting (ZBB) of the Carter Administration represented efforts to link budgetary decision making and public policies on program outcomes, as demonstrated in evaluation studies (Carman 2008).

More recently, the Government Performance and Results Act (GPRA) of 1993 was an initiative whereby the federal government required federal agencies to improve the effectiveness of their programs and their accountability to the public by focusing on results, service quality, and customer satisfaction. Basically, GPRA requires that “federal agencies improve program management and Congressional decision-making by assembling objective information about program results and achievement of statutory objectives” (Federal Transit Administration 2003).

GPRA was unique in the evolution of evaluation legislation because it was administered by the U.S. Office of Management and Budget instead of the line Executive agencies and thereby directly linked budgeting decisions in the White House to program performance results. Another way that GPRA tried to achieve organizational reform was reflected in the requirement that federal agencies produce a strategic plan that included a performance element that would measure how each federal program was meeting its objectives (Carman 2008).

While GPRA illustrates the growing support for mandated program evaluation, there has been a lack of agreement as to methodology for implementing it. As a result, evaluation mandates generally have avoided stipulating a specific mode of data collection and standardization in the design of evaluation research (Manski 1990).

FTA’s Before and After Study Mandate

As a response to GPRA, FTA believes that the Before and After Study will assist the agency in meeting the intent of GPRA and to carry out its responsibilities to document the accomplishments of the New Starts program (Federal Transit Administration 2003).

Therefore, in keeping with the spirit of GPRA, in 2001 FTA issued its *Final Rule on Major Capital Investment Project*, mandating that New Starts projects conduct a Before and After Study. Specifically, the federal rule requires project sponsors who obtained a Full Funding Grant Agreement from FTA for New Starts projects submit a complete plan describing how they will collect and analyze Before and After information on the impacts of their projects and the accuracy of their forecasts.

To further strengthen the Before and After Study requirement, Title III of the 2005 national transportation act (SAFETEA-LU) codified the mandate that all New Starts sponsors prepare Before and After Studies. As was required in the Final Rule mentioned above, the SAFETEA-LU legislation mandates that all New Start

applicants produce a plan that will describe the information to be collected and analyzed. The contents of this plan are to provide for:

1. The collection of data on the current transit system regarding transit service levels and ridership patterns, including origins and destinations, access modes, trip purposes and rider characteristics.
2. Documentation of the predicted scope, service levels, capital costs, operating costs, and ridership of the project.
3. Collection of data on the transit system two years after the opening of the new fixed guideway capital project, including analogous information on transit service levels and ridership patterns and information on the as-built, scope, and capital costs of the project.
4. Analysis of the consistency of predicted project characteristics with the "after" data. (Federal Transit Administration 2008)

Therefore, implementing before and after data collection procedures will permit project sponsors to produce an evaluation report that will serve internal and external constituencies by providing insights into the costs and impacts of major transit investments and improving the technical methods and procedures used in planning, forecasting, design, and construction of transit projects (Fisher 2003).

Ultimately, the intent of Congress in mandating this evaluation mandate was to produce Before and After Studies that achieve the following benefits:

1. Strengthen the New Starts program by highlighting the success of individual transit capital investments and the important role that transit plays in improving mobility and quality of life in communities throughout the nation.
2. Identify and transfer lessons learned in planning, implementing, and operating transit fixed guideway investments to agencies planning similar projects. Information generated from the Before and After Studies will enable the sponsors of future New Starts projects to build upon recipients' experiences with past projects including design and operational features that have proven successful, while avoiding options that have been less successful.
3. Identify the strengths and weaknesses in local procedures for predicting transit ridership and estimating capital and operating and maintenance costs, and identify ways that technical methods can be improved to support decision-making for future projects.

4. Imbed within the planning and project development process the data assembly and analysis tasks that are needed to measure predicted and actualized project costs and impacts.
5. Accumulate a source of technical information on the actual costs and performance of major transit investments. (Federal Transit Administration 2008)

Findings of Three Before and After Case Study Examples

The 2003 SAFETEA-LU legislation required that FTA produce an annual Report to Congress that summarizes the results of New Starts Before and After Studies that have been submitted to FTA by transit sponsors. In meeting this Congressional evaluation mandate, FTA has had an “on-again, off-again” experience in obtaining Before and After Studies Reports from project sponsors because “it can take a number of years after a project receives FFGA for a Before and After Study to be completed. It can take several additional months for the project sponsor to synthesize and evaluate all the information collected.” (LaHood 2009). Since the Before and After Studies guidelines require that there be at least a two-year implementation period after a project is opened and before data are collected, the first FTA Before and After Studies Report to Congress did not occur until 2007.

A summary Report was expected in 2006 and 2009 but, due to the circumstances described above, no project sponsor had completed its two-year implementation period for inclusion in those FTA annual reports. In 2007 and 2008, FTA was able to provide summary reports to Congress on the projects described below. Therefore, the following three Before and After Studies have been summarized in FTA’s Annual Report to Congress and represent the universe of all Before and After studies that have been completed to date.

1. Utah Transit Authority: Medical Center Extension (MCE) of the Salt Lake City TRAX light rail system—a 1.53-mile extension of the existing Salt Lake City East-West line running from downtown to the University of Utah, which includes the Medical Center. A Full Funding Grant Agreement for the MCE was signed with FTA in May 2002, and the MCE began operation on September 2003. A draft of the MCE Before & After Study Report was submitted to FTA in December 2006 and was included in its 2007 *Before and After Studies Report to Congress*.
2. The Tri-County Metropolitan Transportation District of Portland, Oregon (Tri-Met)—a light rail transit system that is a 5.8-mile Interstate Metropolitan

Area Express light rail project. A Full Funding Grant Agreement was signed in September 2000 and began operation in September 2004. A draft Before and After Study report was received by FTA from TriMet in November 2007 and included in its 2008 *Before and After Studies Report to Congress*.

3. Puerto Rico Highway and Transportation Authority's Tren Urbano Heavy Rail Project—a 10.7-mile double track heavy rail/ train system in San Juan region. A Full Funding Grant Agreement was signed in July 1999, and the project began full operation in June 2005. FTA received the draft Before and After Study Report from the project sponsor in March 2008 and included this report in its 2008 *Before and After Studies Report to Congress*.

While providing valuable evaluative information and data on operations of New Starts projects, these three case studies also illustrate some of the procedural and methodological issues that confront project sponsors in implementing an evaluation study mandate.

Capital Cost Findings of Case Studies

The Before and After Study guidelines request that sponsors provide forecasts of project costs (capital, operating, and maintenance) early in the New Starts planning process. Furthermore, two years after completion of the project, the guidelines require that similar cost data be collected in order to make comparisons of the “after” data with the predictions. Table 1 presents a summary of the forecasted (or “estimated”) and actual data that were provided by the sponsors of the three case study projects.

Table 1. Costs and Ridership Data in Three New Starts Transit Projects

	Total Miles of Service	Estimated Capital Costs (millions)	Actual Capital Cost (millions)	Estimated Capital Cost per mile (millions)	Actual Capital Cost per mile (millions)	Estimated # of riders (per day)	Actual # of riders (per day)
Utah Light Rail	1.53	\$89	\$84	\$58.4	\$54.6	4,100	2,640
Portland, OR Light Rail	5.8	\$283	\$350	\$48.8	\$60.3	13,900	11,800
Puerto Rico Heavy Rail	10.7	\$1,250	\$2,250	\$116.8	\$210.3	114,500	24,700

Source: Compiled by author from Federal Transit Administration, Before and After Studies of New Starts Projects: A Report to Congress. 2007 and 2008, Washington, D.C.: U.S. Department of Transportation.

These data supplement the ongoing performance data (called Section 15 data) reporting that is required of all transit providers, with the key difference being that Section 15 data is a uniform annual accounting of costs and service (e.g., cost per mile, cost per passenger, ridership) of the overall transit system, while Before and After Studies provide project-specific longitudinal comparative data (Black 1995).

The New Starts transit projects, as summarized in Table 1, reveal that clearly there is great variation among the projects with regards to their forecasted and actual capital costs. One very important issue that is highlighted in Table 1 is the major capital cost overruns that occurred. For example, the reasons given for the before and after cost discrepancy in the Portland Light Rail project included:

- Change in reporting instructions between the two timelines, requiring \$11.3 million more for start-up and interim financing in final cost.
- Increased number of vehicles purchased.
- Increased costs for communications and signals.
- Increased costs for rebuilding rather than modifying a bridge.
- Increased costs for rights-of-way associated with the number of easements required for implementation. (Federal Transit Administration. 2008).

Puerto Rico's heavy rail project experienced the greatest before and after capital cost discrepancies when compared with the other two case studies, with an 80 percent overrun. The 2008 FTA report claims that this discrepancy is attributed to several factors such as the lack of quality "before" data and operational problems such as:

- The contractor bids were higher than the original estimates.
- As design progressed, the following changes were made in several of the project characteristics: exercise contract options for two additional stations, exercise contract options for adding 10 vehicles, unforeseen site conditions, and refinements to the scope of the project.
- Project delays due to lack of qualified construction personnel, weather conditions (three hurricanes), interface coordination issues, design changes while construction was under way.
- The extended schedule and delays required additional support for the Project Management and Construction Management services consultants as well as additional in-house administrative support.

- Increased right-of-way costs.
- Settlement agreements—all contactors requested additional time and money due to weather, complexity of the project, numerous interface coordination issues, and evolving design control while construction was under way.
- Acceleration payments for contract completion were given to several contractors. (Federal Transit Administration. 2008).

Finally, the before and after capital costs experienced by the Utah Light Rail Transit project demonstrated best practices among the three projects, with the actual capital costs being less than the projected costs. The Utah Transit Authority suggested that the reduction in costs was due to “efficiencies gained by allowing the construction contractor that had just completed the University Light Rail Transit line to immediately initiate construction on this line” (Federal Transit Administration 2007).

Ridership Findings of Case Studies

As was discovered with capital costs, ridership also reflected significant differences when comparing Before and After project data. Table 1 illustrates that in all three case studies, the actual ridership outcomes were much less than projected amounts. For example, Portland’s Light Rail Transit ridership data for 2008 was 15 percent less than expected. The reason for the discrepancy was attributed to the forecast model, which was affected by the following operational problems:

- The actual number of jobs in the corridor was 27 percent less than predicted.
- The travel model output shows that 53 percent of all rail riders were commuters, whereas the results of a transit on-board survey indicated only 40 percent were commuters.
- The park-and-ride modeling assumptions were overly optimistic.
- Predicted rail speeds were 8 percent higher than actual.
- Some transfer and walk connection assumptions were overly optimistic. (Federal Transit Administration 2008)

Due to the fact that Puerto Rico’s project involved construction of a new high capacity, metro subway system, their forecasts for ridership were very high but, ultimately, the project achieved only 23 percent of anticipated riders per day in

the first two years of operation. Some of the reasons for the lower than expected ridership were:

- Observed ridership was 24,700 average weekday rail passengers in Year 1 (2005-2006) and 26,900 in Year 2 (2006-2007).
- Predictions were 114,500 weekday rail passengers in 2010.
- Predictions were based on a project change from 14 to 16 stations plus changes to the surrounding bus network to result in 113,100 weekday rail passengers in 2010.

Furthermore, the forecasting modeling errors in the Puerto Rico project appear to be due to a combination of the following factors:

- The travel model specifications may have been too favorable for use of rail over auto and bus choices.
- The assumed flat fare for riding the rail was significantly less than the actual implemented fare.
- The coded transit network did not adequately represent the private and public bus services that offered the public a competitive alternative to use of rail.
- The predicted travel times were lower than actual.
- The model overestimated the amount of intermodal integration that actually occurred at the rail stations (e.g. the model predicted more than 50% of all rail riders will arrive at a station by a bus rather than walking or driving, but survey data shows the actual number is less than 20%).
- In spite of the model's over-prediction of total rail riders, it under-predicted the number of park-and-ride and kiss-and-ride users, which may have influenced the construction of an insufficient number of parking spaces to satisfy actual park-and-ride demand.
- Population was assumed to grow by 19 percent from 1990-2010, but Census data for the 1990 to 2010 periods shows a growth of only 5.4 percent. (Federal Transit Administration 2008)

Before and After ridership data for the Utah Transit Authority were provided in the 2007 FTA report to Congress and, similar to the capital costs findings, the Utah Light Rail Transit system forecasted ridership that was not realized in project implementation. The reason for this outcome was attributed to problems with

the forecast model, which was implemented by the metropolitan planning organization (called WFRC) and not the Utah Transit Authority.

The Utah project sponsor described these forecasting problems as follows:

Over the course of project planning from 1993 to 2001, the WFRC updated its travel models and in the absence of a requirement for Before and After Studies, retained only sparse documentation of the forecasts. The many details of the forecasting process and of the key drivers of forecasts were not archived and were no longer available when the requirement for a Before and After Study was established. Further because the Medical Center Extension project was not treated as a separate project during the planning stages, forecasts of ridership are an undifferentiated component of the forecasts for the entire University LRT Line (Federal Transit Administration 2007).

The discrepancies identified above between forecasted and actual cost and ridership data is not a surprise to transit planners familiar with the problems associated with transportation forecasting. Through the years, several analysts have criticized the inaccuracies and potential for bias associated with large scale transit project forecasting. As a result, “new generation rail systems have failed to produce the ridership that was promised and ended up costing far more than was forecast” (Pickrell 1989; Cervero 1998).

Lessons Learned from Case Examples

We have shed light on the links between the pragmatic forms of knowledge/concepts used in action and the academic and formal knowledge/concepts disseminated in the literature. The two are not disconnected so the detour via evaluators’ practices and pragmatic conceptualization opens wide perspectives for research and theorization in evaluation (Tourman 2009, 28).

Analyzing the Before and After Studies of transit projects reveals some lessons regarding the practice of evaluation that can help make transit-related mandated evaluation research more effective. The objective of this paper was to describe the characteristics of the Before and After Studies mandate, the findings of the Before and After Studies that have been implemented to date, and analyze the implications of these Before and After Studies in federal the transit field. Therefore, the outcomes of the utilization of pragmatic and academic forms of knowledge as

demonstrated in FTA's Before and After Studies have led to the following lessons learned:

Lesson Learned #1: FTA's Before and After Studies mandate strengthens the validity of FTA's evaluation data by employing a Quasi-Experimental evaluation research design.

Before and After Studies represent an effort on the part of FTA to increase the sophistication of evaluation research design by moving from a Non-Experimental collection of one-time "after-only" data (e.g., Section 15 performance data) to Quasi-Experimental "pre-test and post-test" design. Of course, this approach is not a controlled Experimental design, because the design is lacking random assignment of a sample population and the use of experimental and control groups. Instead, Quasi-Experimental evaluation represents a feasible research design that provides more credible data on the important role that transit can play in improving mobility and quality of life in communities throughout the country (Federal Transit Administration 2008).

Lesson Learned #2: The Before and After Studies experienced difficulties in accurately forecasting costs and ridership, which must be addressed in FTA's data collection and forecasting guidelines.

Previously in this paper, the issue of producing reliable forecasts was discussed as a common problem facing transportation planners. Exacerbating this problem is the fact that the three case studies described included projects that were initiated before FTA had developed clear data collection and forecasting guidelines. Therefore, most projects reported some discrepancies between before and after data and among different transit projects. Specifically:

- The forecasting model that Portland used in the Before and After Study overestimated the percentage of riders who were commuters.
- Portland's park-and-ride and walk-and-ride assumptions were too optimistic.
- Puerto Rico discovered that its travel model favored use of rail over other modes and so ridership in park and ride and bus was underestimated.

In response to the need to collect quality, consistent data, FTA issued guidelines in 2006. Since Utah's study was implemented after the adoption of these data collection guidelines, Utah's relative success in producing more accurate forecast data indicates that these new data collection procedures were helpful in addressing this problem.

Lesson Learned #3: Closer intergovernmental cooperation is needed in implementing mandated evaluations of public programs.

In general, most metropolitan areas in the United States have divided implementation of transit management and planning among separate agencies. Management is usually the responsibility of the regional transit authority, while planning is conducted by the metropolitan planning organization (MPO). This division of responsibility among two different agencies created problems in implementing the Before and After Studies mandate because it required cooperation and coordination among these different agencies. Several of the case study cities identified problems in achieving cooperation such as:

- Utah's MPO did not fulfill its role of collecting and archiving forecasted data.
- Puerto Rico reported that costly delays were caused by problems in coordinating consultants with in-house staff.

In conclusion, the Before and After Studies requirement can provide an important new direction for evaluation of large-scale transit projects if the federal mandate provides clear guidance as to Quasi-Experimental research design, data collection, forecasting procedures and addresses process issues such as intergovernmental coordination. By comparison, the effectiveness of FTA's Section 15 performance reporting procedures have proved to be limited in addressing these issues.

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Web-Based Weapons of Mass Destruction Training for Transit Police

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Abstract

In response to increased terrorist attacks on mass transit systems worldwide, emergency planning and security efforts have intensified. One of the most important planning elements is the provision of training for first-response personnel. Yet few terrorism-related training programs specific to the mass transit sector are available. To address this unmet need, a web-based weapons of mass destruction (WMD) simulation training program, specifically designed for transit police, was recently developed, implemented, and evaluated. Results indicate that this program was effective in improving transit police officers' ability to recognize and respond to WMD simulations.

Introduction

Terrorist attacks targeting transit infrastructure document the inherent vulnerability of these systems. They also underscore the important role of emergency preparedness in minimizing morbidity, mortality, and structural damage (Sahm 2006; Okumura, Ninomiya, and Ohta 2003; Bolling et al. 2007; Intelligence and Security Committee 2006). Beyond the immediate impact on the intended target, "transit terrorism" can instill fear and dread among the transit ridership and public at large (Litman 2005). This fear may translate into reduced ridership with resultant

economic, social, and political ramifications (Litman 2005; Dolnik 2007). While any multi-passenger mode of conveyance may be the target of transit terrorism, historically, public transportation buses have most often been attacked. Between 1920 and 2000, 40 percent of terrorist attacks worldwide involved buses, with explosives most commonly used (Jenkins and Gersten 2001). Heavy rail, including commuter trains and subways, has also been the target of transit terrorism. High passenger volumes, predictable peak periods (e.g., rush-hour), easy accessibility, anonymity, and lack of security screening of passengers make all forms of mass transit potential targets of terrorism (Dolnik 2007; Waugh 2004; Fink, Taylor, and Loukaitou-Sideris 2005; Jenkins and Gersten 2001).

In 1995, the first large-scale WMD attack involving mass transit took place in Tokyo. Shinrikyo terrorists released sarin gas on the subway system during rush hour, resulting in 12 deaths and thousands of injuries (Sahm 2006). Disorganized command and miscommunication at the scene increased the risk of exposure to passengers, transit workers, and first responders. Exposed first responders even served as a source of secondary exposure to others, including those waiting to be treated in hospital emergency rooms (Jenkins and Gersten 2001). Following this attack, major changes were implemented in Japan to enhance emergency response to WMD attacks. Scene demarcation, personal protective equipment, information sharing and coordination, and education and training are now standard features of Japan's chemical disaster response plan (Okumura, Ninomiya, and Ohta 2003).

Nine years later, on March 11, 2004, the Red Nacional de Ferrocarriles Españoles (RENFE) rail system in Madrid was the target of transit terrorism. The attack was perpetrated by Al Qaeda operatives, who detonated remotely-controlled explosives (Sahm 2006). Although Madrid's emergency response plan was put into effect within an hour of the attack, the fatality rate was high, with close to 200 individuals killed and over 1,000 others injured (Bolling et al. 2007). Officials reported that the rapid and coordinated efforts of transit police, municipal agencies, and the national army helped to prevent even more deaths and casualties. Since the attacks, closed-circuit television (CCTV) monitoring of the RENFE transit system has greatly increased, along with improvements to its police training program (Taylor et al. 2005).

Another country that has experienced large-scale transit terrorist attacks in recent years is Great Britain. Historically, the London underground and commuter rail system has been targeted by the Irish Republican Army (IRA) terrorist group. Consequently, the transit system has long been the focus of intense, ongoing counter-

terrorism activities (Jenkins and Gersten 2001). In spite of this high level of security, the system was breached. On July 7, 2005, suicide bombers detonated explosives on subway trains and a double-decker bus during the morning commute in London (Sahm 2006). Fifty-two individuals were killed and approximately 700 were injured. Following these events, a report by Great Britain's Security and Intelligence Committee noted that while the nation's intelligence agencies and security infrastructure, including law enforcement and counter-terrorism units, were not liable for the attack, improvements to security were absolutely necessary (Intelligence and Security Committee 2006). In response, counter-terrorism efforts for mass transit further intensified. More comprehensive national and local emergency management plans were developed, including better training on recognition and response to possible chemical, biological, radiological, nuclear, and explosives (CBRNE) terrorism attacks (Home Office of the United Kingdom 2009).

In response to transit terrorism, many other transportation systems worldwide similarly improved their basic security measures. More extensive controls, improved communications, and increased presence of law enforcement on trains, platforms, and stations are standard in many systems. Surveillance equipment is increasingly common on all forms of mass transit. In addition, passenger screening and public awareness campaigns also have been instituted. Education of transit workers is also a priority for many transit systems (Sahm 2006). However, all of these preventive measures require substantial financial resources. Anti-terrorism funding is limited and in demand by many different sectors. For example, in the United States, improvements to transit security were made in the wake of the September 11 attacks, but the bulk of the terrorism preparedness and response funding focused primarily on aviation security (Waugh Jr. 2004; Office of the New York State Comptroller 2008).

Further mass transit security improvements are planned for the U.S., but increased costs and competing needs have led to delays. A good case in point is the security funding constraints faced by the Metropolitan Transit Authority (MTA), which oversees the mass transit system connecting New York City (NYC) to Long Island and Connecticut. MTA security increased dramatically following the World Trade Center attack, which destroyed 1,400 feet of subway track along 4 subway lines and led to the closure of 11 stations (Jenkins and Edwards-Winslow 2003; Mammen 2007). Additional security measures were implemented in NYC following the London terrorist bombings (Office of the New York State Comptroller 2006). Currently, the proposed MTA capital security plan budget is enormous, with

projected costs in excess of \$740 million for the first of two phases (Office of the New York State Comptroller 2008). Other security improvements, including training, continue to be expensive. Therefore, financial constraints make it even more important for training programs to be cost-effective.

One low-cost training method that is increasingly popular is the web-based program. This format is especially suitable for incorporating simulated scenarios, that is, simulations of real events. Because simulations require decision making on the part of the learner, with feedback immediately given, students are more engaged and learning is enhanced (Cole 1994). Classroom-based simulation training programs have been successfully used to educate first responders and healthcare providers on a variety of topics (Subbarao et al. 2006; Summerhill et al. 2008; Idrose et al. 2007), and the adaptation of simulation exercises into the web-based format is relatively simple. Not only are simulations well-suited for emergency preparedness training, but the web-based platform is an efficient method for training large numbers of students.

To address the need for low-cost, effective training of transit police officers, the study team developed, implemented, and evaluated a state-of-art web-based simulation training program using a pre-post intervention study design.

Methods

Human Subjects Protection

The study protocol was approved by the Columbia University Medical Center Institutional Review Board (IRB), State University of New York College of Optometry IRB, and the Human Research Protection Office of the U.S. Army Medical Research and Materiel Command. All of the subjects provided informed consent prior to participation.

Curriculum Development

A Curriculum Development Team, representing experts in WMD, emergency preparedness, emergency medicine, and transit security, was formed. The resulting training curriculum reflected both local and national policies and procedures on WMD recognition and response. The curriculum consisted of two training modules: (1) an introduction to basic WMD knowledge and event detection, and (2) presentation of three simulation scenarios with embedded test items. Each of the scenarios presented potential terrorist-related events occurring in major mass transit transfer stations. The scenarios addressed three different types of events:

a sarin gas release, an anthrax release, and an explosion of a radiological dispersal device (i.e., “dirty bomb”).

During the simulations, participants were presented with decision points in which they were requested to choose a course of action. Participants choosing correctly advanced through the story line. Those with incorrect responses were provided with the correct answer and an explanation, and directed to an online resource for additional information. The training program was pilot-tested on police personnel, and changes were made to both the training modules and assessment tools based on their responses and suggestions.

Module & Scenario Adaptation

The modules and scenarios were finalized in PowerPoint and then adapted for the project website using Adobe Photoshop® and Adobe Dreamweaver® software for module design, development, and deployment. The programming languages used were XHTML for markup, CSS for layout, and PHP for MySQL database interaction, dynamic content, and data validation. JavaScript™ also was used for client-side data validation. User tracking and reports were available as dynamically-generated Microsoft Excel® files. The online version of the modules also was pilot-tested for ease of use. (Copies of the training program in Microsoft PowerPoint® format and all study materials may be obtained at no cost from the corresponding author.)

Study Population

The Metropolitan Transit Authority Police Department (MTAPD) is the agency that polices the Metro-North Railroad, the Long Island Rail Road, and the Staten Island Railway. The MTAPD has jurisdiction in 14 counties and 2 states (NY and CT) (Metropolitan Transportation Authority 2009), which includes over 4,500 square miles. While it is primarily responsible for the commuter railroad in these two states, it has jurisdiction over the counties through which the trains run. In 2007, the MTA recorded over three billion passenger-rides, the highest of all transportation systems in the U.S. (American Public Transportation Association).

At the time of participant recruitment, the MTAPD employed approximately 550 officers. The training program was distributed to the entire MTAPD police force (nine districts) in January 2008. It was accompanied by an email from a high ranking officer of the MTAPD that encouraged all officers to participate. Recruitment was coordinated by each district administrator, and data collection continued until June 1, 2008.

Measures to Increase Response Rate

Participants who did not complete the entire training program after initially registering were sent weekly reminders. A similar approach was taken for the one-month follow-up questionnaire. Those who completed all three phases of testing were eligible to win an iPod Nano (odds of winning were 1:100). Any request to be removed from the email list was promptly honored.

Assessment Measures

To determine the effectiveness of the training program, assessment tools (i.e., pre-test, post-test, one-month follow-up test, and program evaluation) were developed and implemented. The pre-test was given before the training program and the post-test and evaluation immediately after, and the follow-up was given one month later. Key outcome variables included change in knowledge from the pre-test to post-test and from the pre-test to follow-up. The overall 13-item knowledge scale consisted of 2 subscales: WMD recognition (8 items) and WMD response knowledge (5 items) (see Table 1 for a description of the items). An internal consistency estimate of standardized responses to the overall knowledge scale yielded a Cronbach alpha of 0.62 (95% CI = 0.57 - 0.67). For the recognition subscale and response subscale, internal consistency estimates of standardized responses yielded Cronbach alphas of 0.55 (95% CI = 0.48 - 0.60) and 0.38 (95% CI = 0.29 - 0.46), respectively. The effectiveness of the training was determined by comparing pre-test to post-test scores and pre-test to follow-up test scores. Long-term retention was measured by comparing pre-test to follow-up test scores.

Table 1. Description of WMD* Knowledge Items

Recognition

1. Five types of WMDs
2. Agent used as bioterrorist weapon
3. Key elements of a dirty bomb
4. Key parts of an incendiary device
5. Chemical agent that has been used as a WMD
6. Chemical agent facts
7. High-risk, potential target of a terrorist attack
8. Indicator that a chemical terrorist attack occurred

Response

9. Use of radiation detectors that officers are issued
 10. Isolation zone designation of an area containing a highly suspicious package
 11. "Hot" zone designation after an explosion
 12. Patrol officer's first response in the event of a terrorist attack
 13. After being exposed or possibly exposed to any terrorist agent, officer's response before returning to active duty
-

*WMD = Weapon of Mass Destruction

Data Analysis

A total of 540 individuals participated in the baseline assessment, online training, and post-test. Questionnaires missing substantial amounts of data on the pre-test and post-test or who did not provide consent were excluded from the analysis, resulting in a final sample of 502 participants (greater than 90% of the total available sample). Roughly one-fifth of the sample (22%, $n = 108$) completed the one-month follow-up. All data were entered into a database and then reviewed by a data manager to ensure accuracy of data entry. Data editing was followed by basic descriptive analysis of the data, including the calculation of means, medians, percentages, proportions, and standard deviations. Level of significance was set at an alpha level of 0.05, two-tailed. Dependent t-tests were used to detect significant mean differences in scores for all scales from (1) pre-test to post-test, to assess increase in knowledge, (2) post-test to follow-up test, to assess knowledge retention, and (3) pre-test to follow-up test, to assess net gain in knowledge. Prior to analysis, assumptions for normality and equal variances were tested. The distributions of all sample groups were consistent with populations that are normal. Effect size was calculated using Cohen's (1988) d statistic (Cohen 1988). Pearson's chi-squared tests were used to test the significance of relations between categorical items. Odds ratios were calculated where appropriate. All analyses were conducted using SPSS 16.0.1 (SPSS Inc. 2008).

Results

Participants ($N=502$) completing the pre-post phases of the study represented all districts of the MTAPD. Most respondents were male (90%), with an average age of 39 years (ranging from 23 to 61 years). A majority (91%) reported at least some college or higher levels of education. Most (81%) participants were police officers assigned to patrol units, although 19% were of higher rank (e.g., sergeant, detective lieutenant, etc.). Average tenure with the MTA in any capacity was 9.4 years. Many participants (77%) had received prior WMD training and, of these, 53 percent reported 6 hours or more of actual prior WMD training. However, almost a quarter of the sample reported no prior WMD training. Over a third of the sample (37%) had actual prior large-scale disaster or WMD response experience. See Table 2 for a summary of demographic information.

Table 2. Description of the Sample, MTAPD (N = 502)

Characteristics	n (% reporting)*
Gender	
Male	453 (90.2)
Female	49 (9.8)
Age	
	\bar{x} = 38.5 yrs
	SD \pm = 7.9 yrs
Highest Educational Degree	
High school diploma or GED	44 (8.8)
Some college or bachelor's degree	402 (80.1)
Some graduate school or graduate degree	56 (11.2)
Rank	
Police Officer	401 (80.5)
Sergeant	60 (12.0)
Detective Sergeant	7 (1.4)
Detective Lieutenant	18 (3.6)
Captain	6 (1.2)
Deputy Inspector	2 (0.4)
Chief	4 (0.8)
Length of Time Affiliated with Current Organization	
	\bar{x} = 9.4 yrs
	SD \pm = 6.8 yrs
Length of Time at Current Rank	
	\bar{x} = 7.2 yrs
	SD \pm = 5.6 yrs
Assignment	
Administrative	6 (1.2)
Investigative	38 (7.6)
Patrol	425 (84.7)
Specialty Unit (e.g., Emergency Services Unit)	25 (5.0)
Command	8 (1.6)
Prior WMD Training	
None	118 (23.5)
1-5 hrs	180 (35.9)
6-10 hrs	90 (17.9)
More than 10 hrs	114 (22.7)
Prior First-Responder Training	
Yes	445 (88.6)
No	57 (11.4)
Prior Response to Large-Scale Disaster or WMD Event	
Yes	184 (36.7)
No	318 (63.3)

*Column numbers may not add to 502 due to missing values.

\bar{x} = Mean; SD = Standard Deviation.

On average, participants had high scores (12.0 points out of a maximum of 13.0 points, or a score of 92%) on the overall knowledge set of questions on the pre-test. This indicates a high baseline level of general WMD knowledge. Scores also were high on the pre-test for the subset of items related to recognition of WMD events (7.3/8.0, 91%) and response to WMD scenarios (4.7/5.0, 94%).

Overall Knowledge Assessment

Results of the dependent t-test indicated that there was a statistically significant mean difference between overall scores on the pretest and post-test, $t(501) = 9.3$, $p < 0.001$, $d = 0.41$ (95% CI = 0.33 – 0.50). Assessment scores significantly increased immediately following training from pre-test (Mean [M] = 12.0, Standard Deviation [SD] = 1.4) to post-test (M = 12.6, SD = 0.9); thus, the training was effective at increasing knowledge. Furthermore, for individuals who completed all three waves of testing, knowledge was retained from the post-test (M = 12.7, SD = 0.6) to follow-up (M = 12.6, SD = 0.9), as there was no statistically significant difference between assessment scores, $t(107) = -1.14$, $p = 0.26$. In terms of net gain in overall knowledge, there was a significant difference between assessment scores at pre-test and follow-up, $t(107) = 3.0$, $p < 0.01$, $d = 0.45$ (95% CI = 0.26 - 0.64), with assessment scores significantly increasing from pretest (M = 12.3, SD = 1.1) to follow-up test (M = 12.6, SD = 0.9).

WMD Recognition

For the eight-item WMD recognition scale there was also an increase in knowledge after training, $t(501) = 7.7$, $p < .001$, $d = 0.35$ (95% CI = 0.26 - 0.43). Specifically, WMD recognition subscale scores significantly increased from pre-test (M = 7.3, SD = 1.1) to post-test (M = 7.7, SD = 0.7); thus, the training was effective at increasing WMD recognition knowledge. Knowledge of recognition of WMDs was also retained at follow-up; there was no statistically significant difference in recognition subscale scores at post-test (M = 7.7, SD = 0.6) and follow-up test (M = 7.7, SD = 0.7), $t(107) = -0.37$, $p = 0.72$. Furthermore, scores on the recognition subscale did significantly increase from pre-test (M = 7.4, SD = 1.0) to follow-up test (M = 7.7, SD = 0.7), $t(107) = 2.65$, $p < 0.01$, $d = 0.35$ (95% CI = 0.16 - 0.54); thus, there was an overall net gain in WMD recognition knowledge for participants who completed the one-month follow-up.

WMD Response

Results from the dependent t-test revealed a significant difference between WMD response subscale scores from pre-test ($M = 4.7$, $SD = 0.6$) to post-test ($M = 4.9$, $SD = 0.3$), $t(501) = 7.8$, $p < 0.001$, $d = 0.35$ (95% CI = 0.26 – 0.44); the training was effective at increasing WMD response-specific knowledge. In addition, knowledge of WMD response was retained from the post-test ($M = 5.0$, $SD = 0.1$) to one-month follow-up test ($M = 4.9$, $SD = 0.4$), as there were no significant differences between subscale scores, $t(107) = -1.9$, $p = 0.06$. Scores on the recognition subscale were not significantly different from pre-test ($M = 4.8$, $SD = 0.4$) to follow-up test ($M = 4.9$, $SD = 0.4$), $t(107) = 1.73$, $p = 0.09$, indicating that there was no significant gain in WMD recognition knowledge from baseline to follow-up.

Participants whose length of time at their current position in the MTAPD was below the mean (7.2 years) were almost two times more likely to increase their knowledge of proper response to WMD scenarios from pre-test to post-test immediately following training in comparison with participants whose time at their current position was above the mean, $X^2(1) = 5.4$, $p < 0.05$, $OR = 1.9$ (95% CI = 1.1 – 3.3).

Scenario Simulations

Regarding the 11 decision points in the simulation scenarios, on average, more than 90 percent of the participants made the correct decision points.

Follow-up Test

Follow-up tests were completed by 108 participants (22%), and some differences were noted between participants who did not participate at follow-up and those who did. Police officers were two times less likely to complete one-month follow-up tests than MTAPD participants from all other ranks, $X^2(1) = 8.2$, $p < 0.01$, $OR = 2.0$ (95% CI = 1.2 – 3.4). Participants with less than six hours of prior WMD training were almost two times less likely to complete the follow-up than participants with more prior training, $X^2(1) = 7.2$, $p < 0.01$, $OR = 1.8$ (95% CI = 1.2 – 2.8). Furthermore, MTA police officers who never responded to a large scale disaster or WMD event were two times less likely to complete the follow-up than those who had prior disaster response, $X^2(1) = 10.6$, $p = 0.001$, $OR = 2.0$ (95% CI = 1.3 – 3.1). Last, there was a difference in pre-test scores for police who followed-up and those who did not; police who did not follow-up tended to score lower on the pre-test ($M = 12.0$, $SD = 1.4$) than those who did follow-up ($M = 12.3$, $SD = 1.1$), $t(216.5) = 2.0$, $p < 0.05$, $d = 0.22$ (95% CI = 0.007 - 0.43). No significant differences were found between police who completed the follow-up test and those who did not on age,

gender, education, tenure with the MTAPD, length of time at their current position, current assignment, and prior first-responder training variables.

Evaluation

Participants (N=502) provided very positive feedback on the program evaluation. A large majority (92%) of police indicated that the training program reinforced their understanding of WMDs. Eighty-eight percent reported that the use of scenarios in the simulation exercises was especially helpful in improving their understanding of WMDs. Most of the sample (94%) indicated that the training described realistic scenarios and events. Eighty-one percent of MTA police also indicated that they felt more confident in their ability to respond to a WMD event following this training.

Discussion

This web-based WMD preparedness training for transit police was effective in increasing knowledge. Increased knowledge scores (from pre-test to post-test) were noted for the overall assessment, WMD recognition items, and WMD response items. Furthermore, for participants who completed all three waves of testing, knowledge was retained for overall and domain-specific knowledge at the one-month follow-up. There was a net gain in knowledge (from pre-test to follow-up test) on the overall WMD assessment and WMD recognition items. Because the baseline level of knowledge was very high, the improvement was small, yet statistically significant. The estimates of internal consistency for the 13-item assessment and WMD recognition and WMD response subscales were tolerable, given the high scores on almost all baseline items (and thus limited variability). Consequently, a high alpha value was not expected, yet the results were still significant. In addition, this training program received a positive evaluation. Most participants felt the scenarios were realistic illustrations of WMD events and also helpful in reinforcing their knowledge and building their confidence. Future training should include more difficult test items at the pre-test level, as this will allow for more robust measures of improvement.

Although the training was generally effective for all demographic groups, it was especially so for participants with fewer years of tenure on the job. Therefore, the training program might be most appropriate for new recruits, and a more difficult, advanced program might be better suited for more seasoned officers. To improve

follow-up testing response rates, better incentives might be used. If training and follow-up testing are mandatory, poor response rates may be eliminated.

Limitations

The study was conducted with transit police affiliated with the MTA in New York City, and these officers may have had more disaster response experience than transit police in other cities. Therefore, this program and its effectiveness may not be generalizable across all transit agencies in the United States. However, the basic WMD knowledge module and scenarios should be applicable across a wide range of agencies and cities, and further study of other urban police forces would be useful in documenting this.

Conclusions

The threat of transit terrorist attacks involving WMD and the potential vulnerability of transit systems worldwide make security and emergency response preparedness important. Training of transit police and first responders can help increase the safety and security of passengers and transit workers. The approach we describe here is an effective and low-cost method for training an urban transit police force on the general recognition and appropriate response to WMD events. This web-based training program, with embedded performance measures, could be adapted easily to fit the needs of other first responders, such as transit workers. It is also easily modifiable to meet the needs of individual transit police departments. Online training should also be supplemented with hands-on practice and refresher trainings to increase retention of knowledge.

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Night-Time Operations in Transit Systems: Evaluating the Athens Metro Owl Services

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Abstract

Public transport operators make significant efforts toward improving the quality of operations by upgrading and maintaining infrastructure and rolling stock, training personnel, and offering better and more responsive services to passengers. Among these responsive services is the extension of service at night (night-time extension) whose goal is to serve night-time demand for passengers. This paper examines, analyzes, and evaluates the performance and quality of the Athens Metro night-time service extension for a two-month trial period. Based on ridership estimates and extensive passenger satisfaction surveys, results indicate that the night-time extension attracted a considerable number of passengers who previously used their private automobiles for the same trips and that users were highly satisfied with the service.

Introduction

Public transportation systems have long been considered the best alternative to automobile transportation in large urban areas; their ability to carry large numbers of passengers while occupying limited urban space at a lower (unit) cost and with far fewer environmental impacts are advantages that make transit

suitable and desirable for urban transport operations (Sinha 2003; Vuchic 2004). Demand, however, is closely related to customer satisfaction by the services provided; improved quality of service, such as higher reliability and adequate service frequencies, is critical for shifting passengers to public transportation (Friman and Felleson 2009; Eboli and Mazzulla 2009).

In this context, public transport operators frequently make significant efforts towards improving the quality of operations by offering new and improved services to passengers. Among these new services is extended operating hours into night, with the goal of serving passengers who otherwise would not use transit (the so-called “transit owl services”) (Faria and Smith 1996; Gwiazdzinski 2006; Reinhold and Kearney 2008). Indeed, a number of European, Australian, and U.S. cities have established public transportation night-time operations: Paris, London, Melbourne, and Amsterdam, for example, have late-night bus lines, while the metro systems of Athens, Berlin, Barcelona, Copenhagen, New York, and Washington, D.C. are among those systems that have extended service hours past midnight. Examples of night-time metro operations for European cities appear in Table 1. (The interested reader is referred to ELTIS web portal www.eltis.org for further information on such services in Europe.) Anticipated gains related to transit owl services focus on the potential reduction of auto accidents by decreasing the use of private vehicles at night and averting the combination of drinking and driving. Moreover, such services have a distinct social role since they (a) allow low-cost transportation during night-time hours, (b) can facilitate transit’s captive passengers, and (c) may generate new jobs in the transit sector (TRB 1998a).

Table 1. Night-Time Metro Operations for Some European Cities

City	Weekday	Weekend	Notes on Weekend Timetable
Barcelona	05.00-24.00	05.00-02.00	Friday and Saturday night
Berlin	04.00-01.00	All night	Friday and Saturday night
Hamburg	04.00-24.00	All night	Friday and Saturday night
Lisbon	06.30-01.00	06.30-01.00	-
Madrid	06.00-02.00	06.00-02.00	-
Munich	04.10-01.30	04.10-02.30	Friday and Saturday night
Paris	05.30-01.15	05.30-02.15	Saturday night

Source: Metro systems web sites, ELTIS web portal <http://www.eltis.org>

While transit owl services are becoming popular in large urban areas, there has been only limited research and in-depth investigation on this topic; Miller (1984), for instance, evaluated and proposed a novel redesign for night-time transit service for Salt Lake City County in the early 1980s. Gwiazdzinski (2006) discussed elements of night-time mobility and transportation services and potentials. In a recent study, Currie and Loader (2009) analyzed night extension of bus services for the Melbourne bus transit system; the authors reported that the extension had a considerable positive effect on overall transit ridership.

In early 2008, the Athens Metro authority extended service for two hours (12:30-2:30 a.m.) on Fridays and Saturdays for a two-month trial period. Their effort aimed at (a) improving access to recreational/night entertainment areas in downtown Athens that suffer from inadequate road infrastructure and limited parking spaces and (b) providing alternative transportation to people not wanting to use their private automobiles (possibly because of alcohol consumption). It should be noted that while Athens has strong recreational and night-entertainment activities year-round, after-midnight transportation traditionally has been available only to private vehicle and taxi users (prior to the trial extension period).

This paper examines, analyzes, and evaluates the performance and quality of the Athens Metro night extension of service for its two-month trial period. More specifically, based on the results of extensive surveys, ridership estimates and passenger satisfaction are derived, analyzed, and discussed. The remainder of the paper is organized as follows: the next section presents details on the set of surveys undertaken throughout the two-month trial period of the night-time extension. Then, results for ridership, trip characteristics, and passenger satisfaction are presented, analyzed, and discussed. Finally, concluding remarks and a short discussion are offered.

Surveys and Data Collection

The survey took place at all stations of the Athens Metro system (Figure 1) each Friday and Saturday night from 11:00 p.m. to 2:30 a.m. for a period of 45 days (February 15 - March 29, 2008). It included two parts, with the first part focusing on passenger boardings and transfers and the second on collecting passenger opinions regarding the extension by means of short personal interviews.

Ridership Survey

The Athens Metro fare collection system can provide only partial data on ridership, since (a) a considerable percentage of riders (over 50% for regular, daytime operations) use monthly and annual fare cards that do not need to be validated when entering the Metro system (and therefore could not be estimated without a survey), and (b) single-ride tickets are validated when only entering a station (implying that transfers had to be counted as well). A direct passenger count process was carried out at each Metro station platform by trained personnel located at pre-specified positions of platform entrances. The number of passengers arriving at the platforms was recorded during fixed time intervals (every 15 minutes); in addition, transfers were counted between all three Metro lines on the transfer corridors between platforms. It should be noted that the task of counting transfers required a detailed inspection of the topology of the transfer stations. Finally, the ridership measurement process needed to be thorough, given the requirement for collecting accurate data regarding boardings and transfers at each platform and station.

Passenger Survey

The second part of the survey included short face-to-face interviews, through which information on passenger and trip characteristics and passenger satisfaction were collected. In particular, collection and analysis of passenger satisfaction using marketing techniques and surveys (TRB 1998b; TRB 1999) has been implemented widely in the last decade for evaluating new transit services; some relevant studies are presented in Iseki and Taylor (2008), Kim and Ulfarsson (2008), Eriksson et al. (2007), McDonnell et al. (2006), Pepper et al. (2003), and Pepper and Ray (1998). Two separate surveys were designed for this purpose, with the first focusing on various trip characteristics (such as travel times, modes used to approach the Metro line, origins and destinations, trip purpose, and so on). The second survey aimed at capturing passenger satisfaction; this was achieved through the part of the interview in which passengers were requested to grade aspects of the night extension on a scale of 1 to 5. The respondents were selected randomly among passengers waiting to board, and the interviews lasted approximately two minutes. A stratified sampling process (Tryfos 1996) was followed, considering gender and age, and a minimum number of 500 interviews was assumed to be adequate for the purpose of both interview-based surveys (3-5% of estimated ridership for that time period; this assessment was based on ridership information collected during the first weekend of the passenger ridership survey). However, the willingness of passengers to participate in the surveys led to over 2,000 completed pas-

senger satisfaction questionnaires and over 2,700 completed trip characteristic interviews. In Table 2, the data collected for each survey are discussed.

Table 2. Collected Data

# Survey Type	Collected Data
1. Ridership Survey	<ul style="list-style-type: none"> • Boardings per station and platform /15min (23:00-02:30) • Transfers per station and platform /15 min (23:00-02:30)
2. Trip Characteristics	<ul style="list-style-type: none"> • Origin and destination stations • Fare type used • Trip purpose • Mode used for night-time transportation before the Metro service extension • Frequency of transit usage • Reasons for using the Metro system during the night-time extension period • Desire to establish a similar extension of service for the Athens bus lines • Gender, age
3. Passenger Satisfaction	<ul style="list-style-type: none"> • Trip purpose • Mode used for night-time transportation previously to the Metro service extension • Frequency of transit usage in general • Mode for accessing the Metro system • Satisfaction with respect to (1: dissatisfied – 5: satisfied for <ul style="list-style-type: none"> Security Frequency Duration of the extension Speed Cleanliness Fare validation Connection with other transport means Overall • Importance of the above attributes • Gender, Age

Ridership

Figure 2 summarizes ridership for the extended hours; the relatively low ridership for March 7 and 8 (compared to the remainder of the period) is expected since this was a long weekend and Athens inhabitants traditionally take long weekends. As can be seen from Figure 2, ridership increased during the trial period. It can be observed that ridership reached 22,000 passengers on Saturdays. Considering that four trains per hour and direction were scheduled and operated during the extension, the total Metro system capacity was $4 \times 4 \times 1,000 = 16,000$ passengers/hour or 32,000 passengers during the (two-hour) extension period. This implies that Metro occupancy for the extension period was almost 70 percent, which was considered very good, given that under normal operations, a 15-minute service for a metro system is rather unattractive to passengers.

Figure 3 indicates that ridership during the extension period is comparable to that of Saturday mornings (8:00-10:00 a.m.). Moreover, ridership for the time period before the extension has increased, consistent with the findings of Currie and Loader (2009). Passengers “attracted” by the service extension use the Metro system for both approaching their destination and returning home, while before the extension they were discouraged from doing so and relied on other transportation modes (private vehicles, taxis). As far as ridership is concerned for specific stations, as can be seen in Figure 4, the largest number of boarding passengers is observed in downtown stations next to recreational areas (stations of Monastiraki, Syntagma, and Kerameikos). Other suburban stations (such as Halandri, for example) exhibit low ridership. It is apparent that during the night-time extension, passengers used the Metro system for departing and returning home; these passenger moved from the Athens downtown to the suburbs but usually not vice versa.

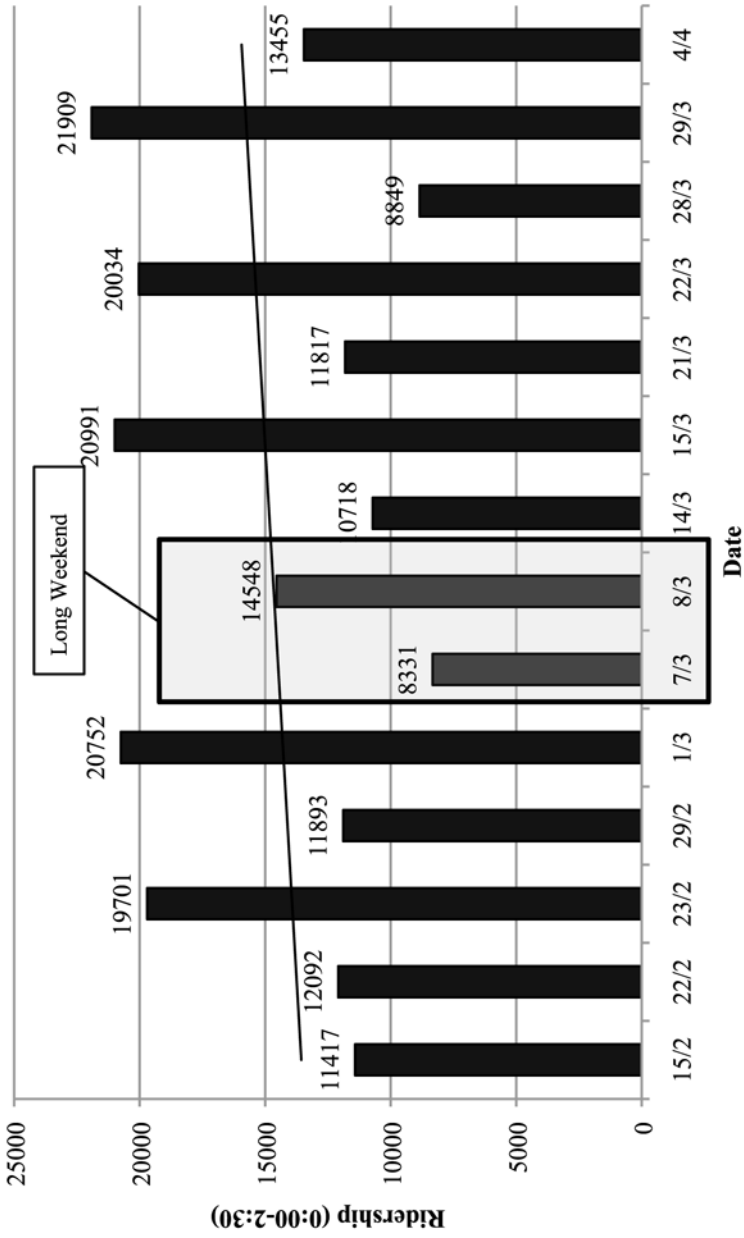


Figure 2. Metro Ridership for the Night-Time Extension Trial Period

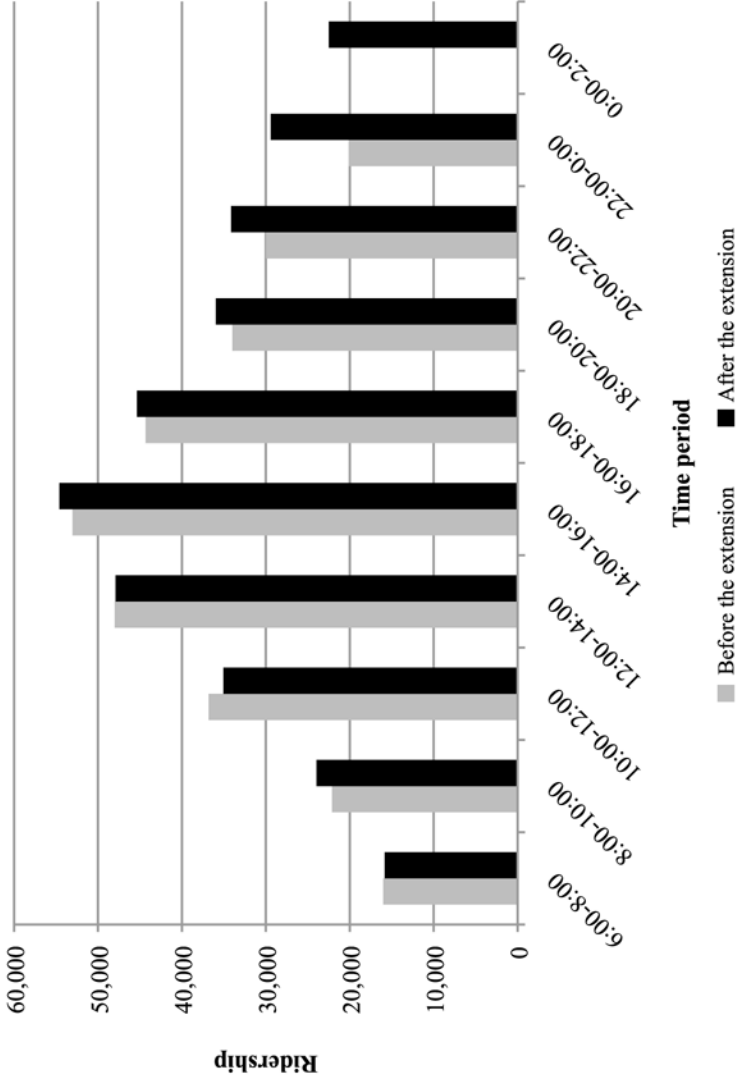


Figure 3. Ridership Distribution for a Typical Saturday before and a Typical Saturday after the Extension Period

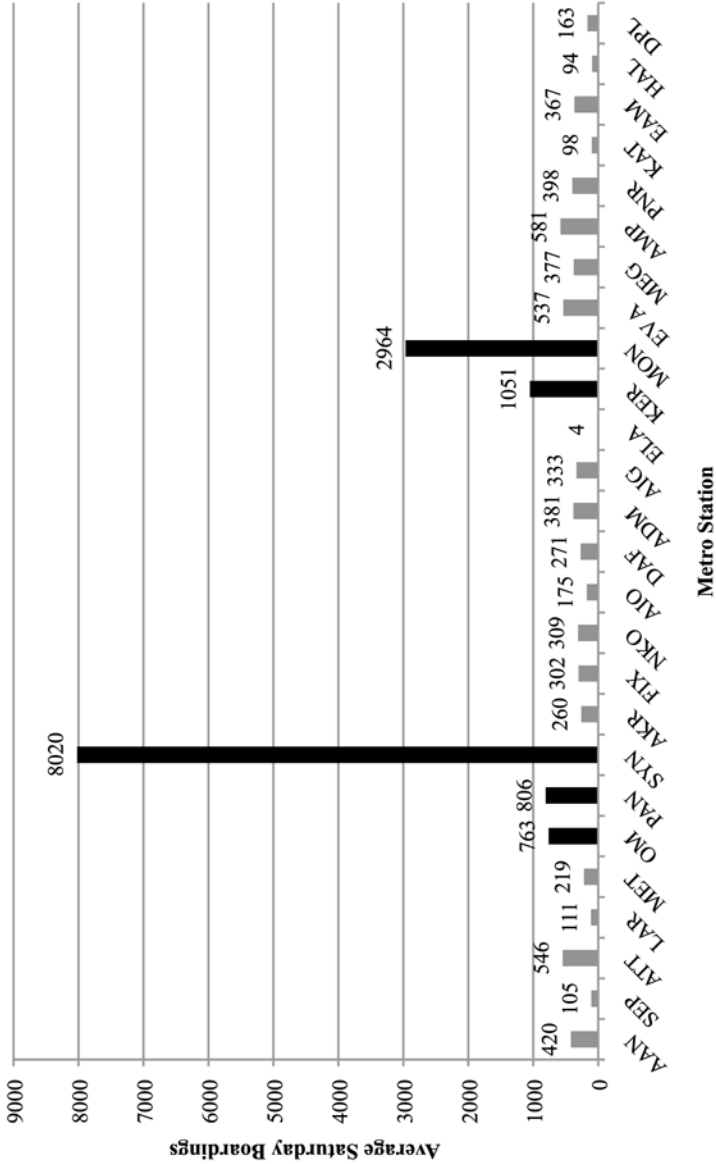


Figure 4. Average Saturday Boardings for Selected Athens Metro Stations

Trip Characteristics and Passenger Preferences

Obtaining information on trip characteristics and passenger preferences was among the main objectives of the study. It was considered important to study the manner in which passengers used the Metro system during the extension period (combination with other modes, origin, destination, trip purpose and so on), since this could help in improving services and studying mode choice behavior in the pre- and post-extension periods. Results indicate that the majority of passengers were 18 to 30 years old (about 67%), and over 75 percent of them had entertainment as their trip objective (they either approached or returned from a night entertainment site; see Figures 5 and 6). What also is interesting is that most of the passengers (almost 90%) are regular public transportation users; they are either captive passengers or passengers preferring transit as a convenient alternative to private vehicles. Figure 7 presents passenger mode choice for the same (or similar) trips in the pre-extension period (note that prior to the extension, a very limited number of night-time bus lines existed).

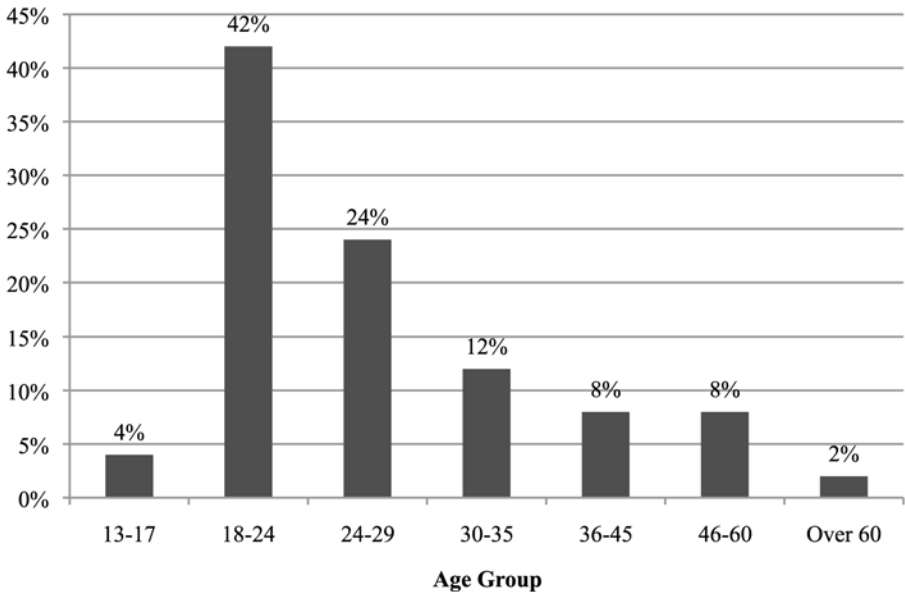


Figure 5. Age Distribution of Respondents

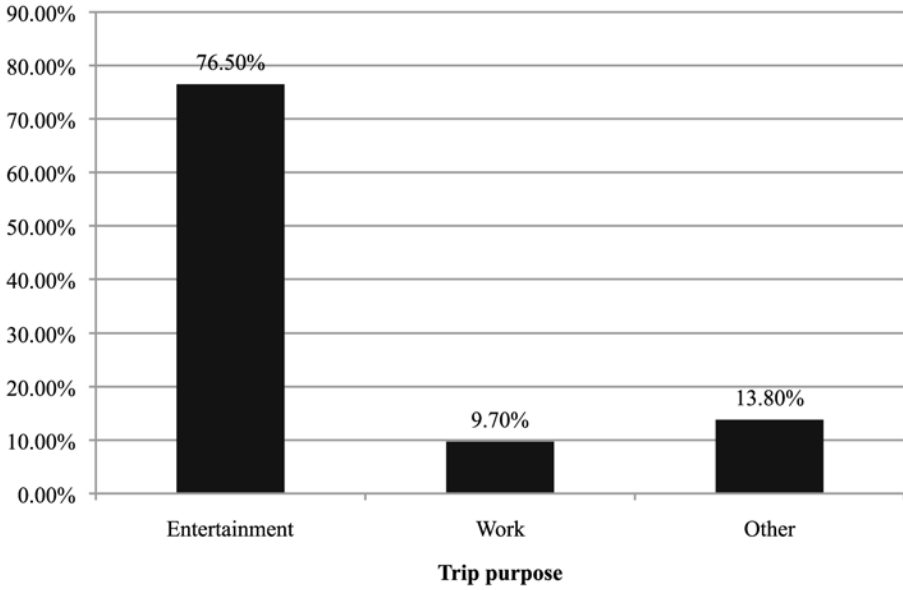


Figure 6. Trip Purpose during Night-Time Service Extension

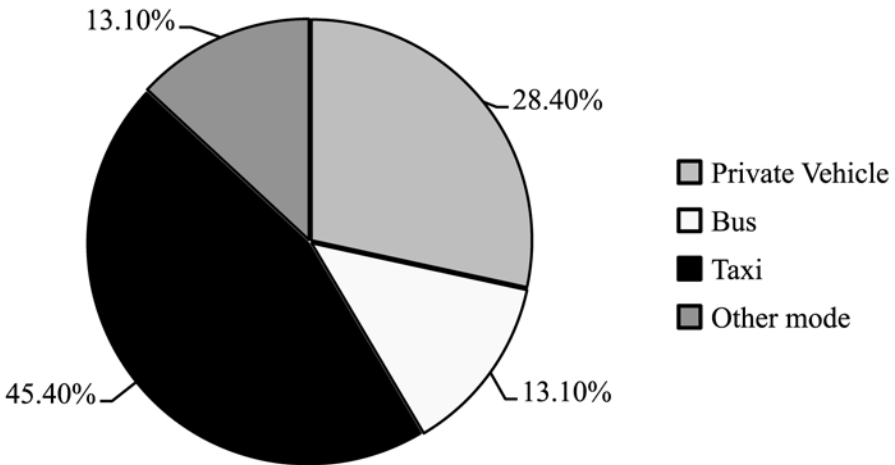


Figure 7. Mode choice prior to Metro System Service Hours Extension

According to the findings depicted in Figure 5, most passengers in the pre-extension period used either their private vehicle (almost 30%) or taxis (45%) for night-time transportation. The Metro service extension resulted in an important reduction in private vehicle and taxi usage. For instance, for a Saturday ridership of approximately 22,000 passengers, about 28 percent of them previously used private vehicles. Assuming an average vehicle occupancy rate of 2 (for night-time transportation), this implies that about 3,000 private vehicles do not enter the Athens downtown areas at night, and higher-risk drivers (young and/or intoxicated) prefer the Metro over their automobile. This also leads to savings in fuel consumption; for example, considering a typical EU passenger car consuming around 9 lt of gasoline per 100 km in the city limits, an average trip length of 8 km and a cost of 1€/lt, more than 25,000 € are saved during each two-hour service extension period from private vehicles alone.

Furthermore, most respondents (70%) seem to use the Metro as the exclusive mode for their night-time journey; a significant number of the respondents (30%) use the buses to reach a Metro station and, subsequently, almost 80 percent of the respondents are attracted to the idea of a similar service extension for the bus system. Figure 8 depicts the reasons for preferring the night-time Metro services.

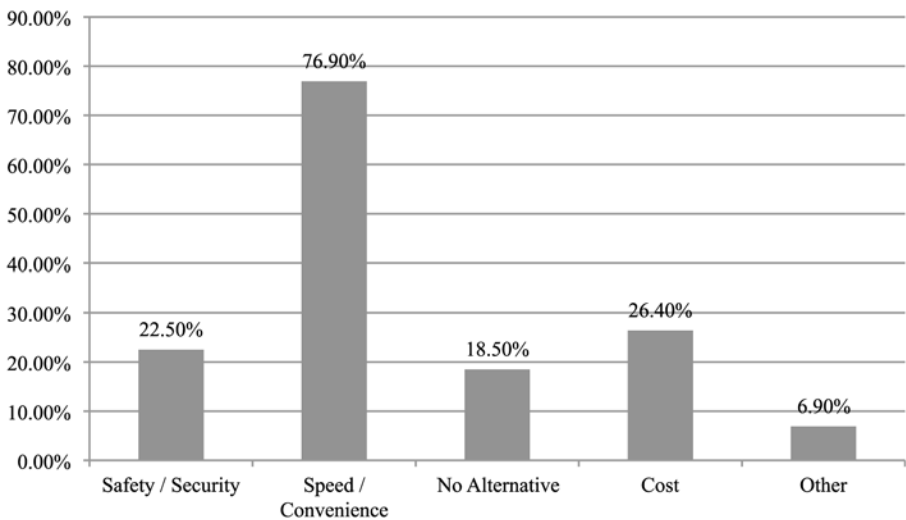


Figure 8. Reasons for Preferring the Metro Night-Time Extension

The results indicate that the primary reasons for using the extension of the Metro services were *convenience* and (low) *cost*. Indeed, night-time traffic congestion in the Athens downtown entertainment areas is a common phenomenon, and parking spaces are limited and very costly. Further, the cost of a Metro ride during the extension period was 0.8 €, while the estimated travel cost with a private vehicle in a Greek urban area is about 0.3 €/km (not including parking cost) (Poriotis 2000) for a trip of 4-5 km on average (a total of 1.2-1.5 € for a trip), plus a minimum of €10 for parking. Finally, taxis during late night operations charge a minimum of 2.7 €.

Passenger Satisfaction

Overview and Methodology

This section focuses on the passenger point of view regarding the quality of Metro night-time services (perceived service quality). Passenger opinions on quality attributes such as security, frequency, extension duration, speed, cleanliness, fare validation checks, and connectivity with other modes, as well as their overall satisfaction, were collected on a scale of 1 (not satisfied) to 5 (very satisfied).

A bi-variate correlation approach was used for assessing the importance of the aforementioned quality attributes against overall satisfaction (TRB 1999; Weinstein 2000; Morfoulaki and Papaioannou 2006). A set of random variables $y = \{y_i\}$, obtaining discreet values of 1-5 is assumed; these variables represent satisfaction for corresponding quality attributes. Also, a random variable y_n represents total satisfaction for the night-time extension. Bivariate correlation examines the degree of correlation between variable y_n and variables y_i . Since the underlying distribution of random variables is unknown, the non-parametric Kendall's Tau-b test is used, and a significance level of 5% is used (Washington et al. 2003). The degree of correlation expresses the strength of the effect of each individual element to the overall satisfaction. Knowing the importance and satisfaction for each element, a quadrant analysis is performed (QUATTRO 1998), aiming at indicating any elements in need of improvement during the night-time service extension (QUATTRO 1998). Quadrant analysis is a widely-used tool that graphically represents the importance of a certain attribute to the overall service in terms of respondent satisfaction with this attribute. Importance rates are normalized, and the mean satisfaction rate for each attribute is estimated and again normalized. A scatter plot is then constructed with the importance versus mean satisfaction pairs (for

each attribute) and divided into four quadrants, where each quadrant indicates whether an attribute is important and/or satisfactory or not.

Preliminary Results

Figures 9 and 10 present passenger satisfaction results for overall satisfaction and satisfaction with connectivity to other modes.

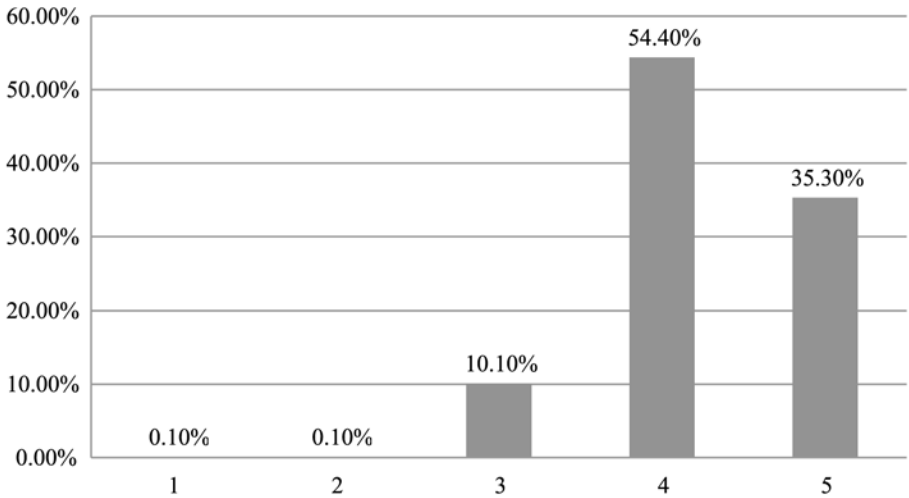


Figure 9. Overall Satisfaction

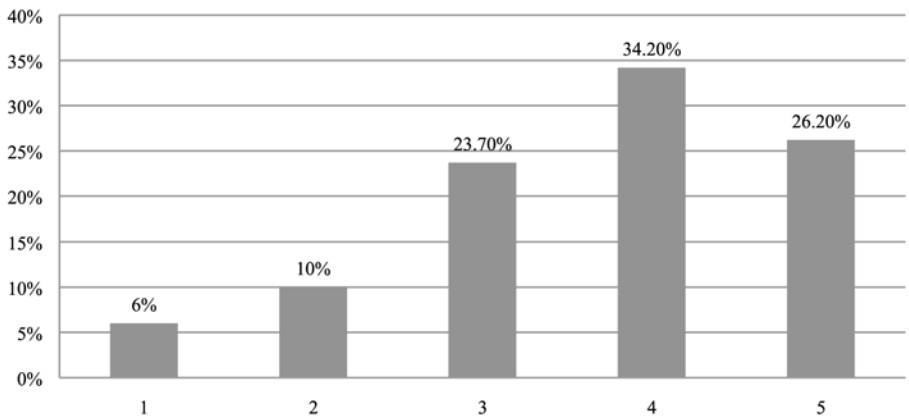


Figure 10. Satisfaction with Connectivity to Other Modes

As can be seen, overall satisfaction was high, while in the case of connectivity with other modes, a good portion of passengers (about 60%) were satisfied, despite the lack of bus lines feeding the Metro system at night. Additionally, the preliminary statistical analysis of results indicated, among other results, the following:

1. Passengers were satisfied (score of 4) or very satisfied (score of 5) with security (90%), speed (96%), and cleanliness (92%).
2. Satisfaction with the duration of the extension and the connectivity with other modes was acceptable (67% and 60%, respectively, of the passengers were satisfied or very satisfied).
3. Satisfaction with service frequency was relatively low (54%).

Overall satisfaction was very high, reaching almost 90 percent of satisfied and very satisfied passengers. It should be noted that the Athens Metro system has a history of providing high quality services; for instance, in 2006, the system was awarded the “Committed to Excellence in Europe” distinction by the European Foundation on Quality Management (EFQM). Frequency-related satisfaction was low; daily service frequency is 2 to 3 minutes during peak and 5 to 7 minutes during off-peak and, as such, a 15-minute frequency for the night-time extension was perceived as inadequate by passengers. However, ridership expectations and the need to balance costs (which were expected to be increased due to higher night-shift wage rates) and revenues (of relatively low fares) led to a compromise in the frequency of service.

Importance of Individual Quality Elements

Results from implementing Kendal’s Tau-b for each quality element are shown in Table 3.

Table 3. Results of Implementing Kendal’s Tau-b for Each Quality Element ($\alpha=5\%$)

Attribute	Degree of correlation with overall satisfaction
Security	0.277
Frequency	0.212
Extension duration	0.203
Speed	0.251
Cleanliness	0.258
Fare validation	0.193
Connection with other modes	0.233

Of particular interest is that factors deemed as important (such as frequency) do not appear to strongly affect overall satisfaction. This is probably due to passengers rating overall satisfaction based on those elements that they find positive; as can be intuitively derived from preliminary data, security, frequency and speed exhibit a very strong satisfaction and tend to drive overall satisfaction to a positive level.

Quadrant Analysis

The scatter plot developed for the quadrant analysis is shown in Figure 11. The quadrant analysis plot presents the relationship between importance and satisfaction of each quality attribute. The vertical axis indicates the normalized value of average satisfaction for each attribute while the horizontal axis its normalized importance.

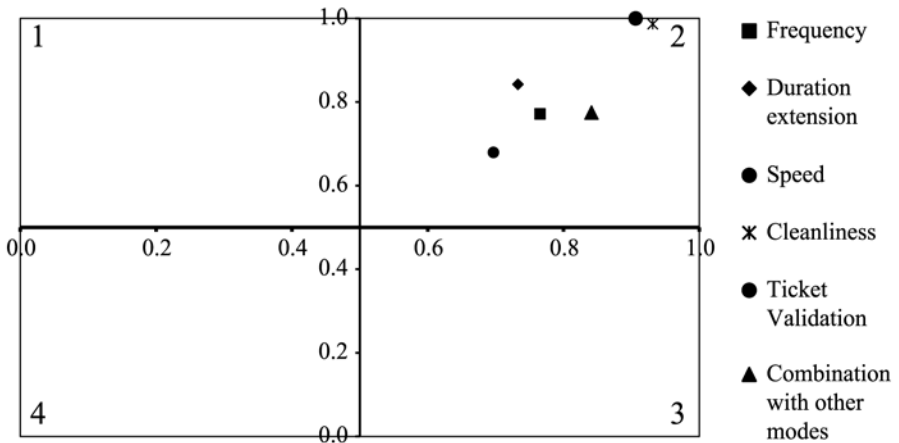


Figure 11. Quadrant Analysis Plot for Metro Extended Service Hours

The plot is divided into four quadrants: Satisfaction—importance pairs in

- ...quadrant 1 imply low importance and high satisfaction
- ...quadrant 2 imply low importance and satisfaction
- ...quadrant 3 imply high importance and low satisfaction
- ...quadrant 4 imply high importance and satisfaction

Obviously, it is desirable to have as many pairs as possible in quadrants 4 and 1, while pairs in quadrant 2 may be tolerable. Any attribute whose pair is in quadrant 3 needs immediate remedial measures. As can be inferred from Figure 11, all

attribute pairs are located in the 4th quadrant. This means that while passengers consider all of them important to the overall quality of the service extension, they are also adequately satisfied by them. Among all attributes, frequency and combination with other modes seem to exhibit the worst performance, by achieving a lower level of satisfaction while being more important compared to attributes such as the duration of the extension and ticket validation.

Conclusions

The objective of this paper is to present an assessment of the Athens Metro night-time service extension during weekends. Ridership data, trip characteristics, and passenger opinions were collected through extended surveys in an effort to estimate night-time passenger profiles and overall satisfaction with the new service. Ridership counts indicated that attracted passengers accounted for around 70 percent of provided capacity, while there was a marked ridership increase in the period before the night-time extension. Most passengers were young and had entertainment as their main trip purpose. Convenience and cost were the main reasons for preferring Metro instead of other modes; the extension of service led to a decrease in passenger car and taxi usage, since 28 percent and 45 percent of the passengers used these two modes, respectively. Passenger satisfaction was very high with the exception of service frequency. However, the strong positive effects of security and convenience were critical for obtaining an excellent overall perceived quality for the system. Furthermore, it should be noted that the Athens Metro system exhibits very high passenger satisfaction (an 81.7% Customer Satisfaction Index according to the European Extended Performance *Satisfaction* Index [EPSI] method) for its regular (day services), as reported by the managing authority (AMEL 2009) and independent studies (Karlaftis et al. 2005).

The issue of the actual trip purpose (entertainment) affecting the mood and, hence, satisfaction of passengers was not raised in this paper. While this possibly could be a fact, passengers still exhibit lower satisfaction for service frequencies and the duration of the extension, compared to daily services (where for instance, frequency satisfaction exceeds 70%, according to AMEL [2009]). This is an indication that while passengers do have a positive view of Metro (day and night-time) services and possibly a good mood, they still are not satisfied with elements of night-time operations and, therefore, their opinions are not influenced by their trip purpose. Trip purpose effect on customer satisfaction for night-time operations is a topic to be investigated by future research.

Overall, during the trial period, the night-time extension attracted a considerable number of passengers, and users were satisfied by the provided services. However, additional measures could prove useful for the extension to be successful in the long run. These could include the initiation of night-time bus feeder service to Metro stations, the improvement of parking facilities around Metro stations, and further discouraging private vehicles from entering the Athens downtown area. In particular, older passengers, currently accustomed to using private vehicles for entertainment-related trips, could be attracted to the Metro system by further improving convenience when accessing Metro stations. Moreover, promotional measures such as advertisement of the night-time Metro service extension and a combination of Metro tickets with other entertainment activities (theater tickets and so on) could attract more passengers to the service.

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Planning and Deploying Transit Signal Priority in Small and Medium-Sized Cities: Burlington, Vermont, Case Study

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Abstract

Innovations in traffic signal systems have generated a great deal of interest in the provision of preferential traffic signal strategies and treatments for transit buses and other vehicles at signalized intersections in cities of all sizes. The primary objective of this paper is three fold: 1) to synthesize the literature of the lessons learned associated with planning and deploying transit signal priority (TSP) strategies in small and medium-sized cities; 2) to demonstrate the application of a micro-simulation model, VISSIM, to assess transit priority impacts in small and medium-sized communities where the required VISSIM input data are often limited; and 3) to present guidelines to aid traffic engineers and transit planners who are considering TSP strategies in small and medium-sized cities. An underlying aim of this paper is to recognize the differences in transit priority planning and deployment in small and medium-sized cities as compared to major metropolitan areas.

Introduction

Advances in traffic signal technologies and other factors have generated a great deal of interest in the provision of preferential traffic signal strategies and treatments for transit buses and other vehicles at signalized intersections in cities of all sizes. To plan and deploy such signal priority strategies and treatments safely and efficiently, careful analyses should be conducted using fundamental traffic engineering and transit management and operating principles. Based on these principles and other considerations, this paper focuses on providing guidance to aid traffic engineers and transit planners in planning and deploying signal priority strategies in small and medium-sized cities.

Objective of the Paper

The primary objective of this paper is three fold: 1) to synthesize the literature of the lessons learned associated with planning and deploying transit signal priority (TSP) strategies in small and medium-sized cities; 2) to demonstrate the application of a micro-simulation model, VISSIM, to assess transit priority impacts in small and medium-sized communities where the required VISSIM input data is often limited; and 3) to present guidelines to aid traffic engineers and transit planners who are considering TSP strategies in small and medium-sized cities. The application of VISSIM is part of a case study on the formulation and evaluation of alternative transit signal strategies in Burlington, Vermont (2000 urbanized area population: 105,365). The impacts of concern in the simulation include bus travel time and delay and side-street queue length.

An overarching aim of the paper is to assist state DOTs and highway and transit agencies in the design and implementation of signal priority strategies for transit buses in concert with other preferential signal treatments, such as those currently in place and being planned for emergency response, including fire and rescue services. Finally, an underlying aim is to recognize the differences in transit priority in small and medium-sized cities as compared to major metropolitan areas. These differences relate to both technical and institutional issues.

TSP Study Results and Lessons Learned

Numerous studies have been conducted in small and medium-sized cities in the United States and Europe to evaluate the impacts of transit priority deployments. These studies fall into two categories. The first includes studies that used simula-

tion to evaluate the anticipated impacts, and the second includes studies where field tests were conducted. The studies that used simulation are summarized in Table 1 (Kamdar 2004; Deshpande et al. 2003; Chang et al. 2003; Dion et al. 2004; Collura et al. 2004; Garrow and Mechemehl 2007; Ova and Smadi 2001). The simulation models most frequently used include VISSIM, TRANSYT, NETSIM, INTEGRATION and SCOOT.

Bus travel time is the most commonly-used measure to assess the impact of transit priority. As shown in Table 1, bus travel time reduction varies significantly among the studies. In a study in Arlington, Virginia (Chang et al. 2003), bus travel time decreased by almost one percent, and in another study in Fairfax, Virginia (Deshpande et al. 2003), the decrease was nearly three percent. On the other end, a study in Fargo, North Dakota (Ova and Smadi 2001) estimated the bus travel time decrease to be 14 percent. Other measures used in some of these studies are side-street queue lengths and side-street person delay, overall vehicle-delay, and stopped delay/vehicle, which estimate the impact of transit priority strategies to non-transit traffic. In most cases, the impact was not significant, excluding the study in Fargo, where side-street person delay increased by 14 percent.

The field studies conducted in small and medium-sized cities are summarized in Table 2 (Ahn et al. 2006; Collura et al. 2004; Zhang 2001; Fox et al. 1998; Deshpande 2003). Measures such as vehicle/person delay, cross street delays, and side-street effects most often showed few significant impacts.

The findings in the studies outside the U.S. are consistent with those within the U.S. and provide additional evidence regarding the beneficial impacts of TSP without significantly impacting overall traffic.

Table 1. Results of Transit Priority Studies Using Simulation

Simulation Studies	Measure	Result
Fairfax, VA-U.S.1 VISSIM (Deshpande et al. 2003)	Bus Travel Time	2.64% decrease
	Time Reliability	3.61% improvement
	Average Queue Length on Side Street	1.28 ft increase (less than one car length); not significant
Arlington, VA Columbia Pike Blvd INTEGRATION (Chang et al. 2003)	Bus Travel Time	0.9% decrease
	Arrival Reliability	3.2% improvement
	Overall Vehicle-Delay	1% increase
Arlington, VA Columbia Pike Blvd SCOOT/INTEGRATION (Dion et al. 2004)	Bus Travel Time	6% decrease
	Overall Person-Delay	8% increase
Bremerton, WA (Collura et al. 2004)	Bus Travel Time	10% decrease
	Stopped Delay/Vehicle	Not significant
Ann Arbor, Michigan NETSIM/TRANSYT-7F (Collura et al. 2004)	Bus Travel Time	6% decrease (for a single bus)
Austin, Texas NETSIM (Garrow and Machemehl 2007)	Bus Travel Time	11% decrease (optimized lower cycle length), 10% decrease (phase splitting)
Fairfax, VA-U.S.1 VISSIM (Kamdar 2004)	Transit Travel Time	0.8% to 4% decrease
	Control Delay	5% to 16% decrease
	Side-Street Queue Length	1.23% increase
Fargo, ND (Ova and Smadi 2004)	Bus Travel Time	14% decrease
	Bus Stopped Delay	38% decrease
	Side-Street Person Delay	14% increase

Table 2. Results of Transit Priority Field Studies

Field Studies	Measure	Result
St. Cloud, Stearns County, MN (Collura et al. 2004)	Bus Delay	43% decrease
	Average Bus Occupancy	24
	Bus Travel Time	13 to 18% decrease
Anne Arundel County, MD MDSHA Opticom (Collura et al. 2004)	Auto Travel Time-Same Direction	9% decrease
	Auto Travel Time-Opposing Direction	4 to 5% increase
Tacoma, WA—Pierce Transit Agency Opticom (Collura et al. 2004)	Bus Travel Time	5.8-9.7% decrease (green extension); 8.2% decrease (green extension and/ or early green)
	Side Street Impacts	Not significant
Charlotte, NC/OPTICOM (Express Buses) (Collura et al. 2004)	Bus Travel Time	4 minute decrease
	Cross Street Delays	Not acceptable
Toulouse, France (Zhang 2001)	Bus Travel Time	11 to 14% decrease
	General Traffic Travel Time	Not significant change
Strasbourg, France (Zhang 2001)	Transit Vehicle Travel Time	4 to 5% decrease
Vicenza, Italy Opticom (Zhang 2001)	Bus Travel Time	23.8% decrease
	Bus Travel Speed	30% increase
Swansea, England SCOOT(Zhang 2001)	Bus Travel Time	2% decrease (passive priority); 11% decrease (greenextension/red trun- cation); no change (green extension)
	Non Transit Vehicle Delay	17% increase (passive priority); 7% increase (green extension/red truncation); 15% increase (green extension)
Leeds, England SPOT (Fox et al. 1998)	Bus Travel Time	10% decrease
	Non Transit Vehicle Travel Time	No Change
Stuttgart, Germany (Deshpande 2003)	Light Rail Transit Delay	50% decrease (conditional priority)
	Private Vehicle Delay	Minimal
Zurich, Switzerland (Deshpande 2003)	Bus Waiting Time	Zero (at 90% of signalized intersections)
Fairfax, VA, U.S.1 (Ahn et al. 2006)	Transit Vehicle Travel Time	3% to 6% decrease
	Intersection Delay	9% to 23% decrease

Simulation Analysis

Transit Priority Scenarios and Evaluation Measures

For the purpose of this research, two different areas of Burlington were examined with the use of the micro-simulation model, VISSIM. The first is Route 15, a four-lane arterial that connects the city of Burlington with the suburbs. The other is the Old North Route, a loop located in downtown Burlington. For the first area, data were available and coded in Sychro and were imported easily in VISSIM. This was not the case for the second location, which is more typical for small and medium-sized cities. In small and medium-sized cities, such Synchron files may not be readily available and thus may require field data collection, which was done in this research. In both cases, the number of routes chosen to deploy TSP is small, constituting another difference between metropolitan areas and small and medium-sized cities. In small and medium-sized cities, planners should be selective in choosing a small number of routes along which TSP may be appropriate, as opposed to large metropolitan areas where there could be many more routes along which TSP might be considered.

Route 15. Two TSP scenarios along Route 15 were evaluated for this research. One included a 10-second green extension for the AM buses in the inbound direction, assumed to be operating under existing conditions, including approximately 30-minute headways. In the second scenario, the inbound buses also may request a 10-second green extension, but the headways were changed to 15 minutes, reflecting the interest among local stakeholders to improve the frequency of bus service along selected bus routes in the region. For this research, only green extensions were considered because the ridership is relatively small compared to the automobile and red truncation is very disruptive and would not be adequately justified. Four major categories of evaluation measures were employed in this simulation analysis: 1) travel time for the bus and vehicle; 2) delay to the bus and vehicle; 3) waiting time for outbound buses; and 4) side-street queue length. The definitions of these measures are summarized in Table 3, as defined in the VISSIM Manual (2005).

The average values for each evaluation measure were calculated based on 20 runs for the first scenario and 8 runs for the second scenario. A statistical analysis using the Student's t-test was first conducted for the absolute values of the samples, followed by a second statistical analysis on the difference of the values. More details on this analysis are presented in Vlachou (2007).

Table 3. Summary of Definitions of the Measures of Effectiveness Used

Measure	Description
Travel Time (sec)	The time required for a vehicle to travel between the first cross-section (start) of the network and the second cross-section (destination), including waiting or dwell times.
Delay (sec)	The average total delay per vehicle is computed for every vehicle completing the travel time section by subtracting the theoretical (ideal) travel time from the real travel time. The theoretical travel time is the time that would be reached if there were no other vehicles and no signal controls or other stops in the network (reduced speed areas are taken into account). The delay does not include passenger stop times at transit stops. However, the loss time caused by acceleration or deceleration because of such a stop remains part of the delay time.
Bus Waiting Time (sec)	All events when a transit vehicle is stopped, excluding passenger interchange stops and stops at stop signs.
Side Street Queue Length (feet)	The maximum queue counted from the location of the queue counter on a link upstream to the final vehicle that is in queue condition.

The average bus travel times for Scenario 1 and Scenario 2 comparing to the base case (i.e., without priority vs. with priority) are shown in Figure 1(a) and 1(b), respectively. In Scenario 1, it appears that the reduction in average bus travel time with priority is almost five percent, and in Scenario 2, this reduction is almost six percent. It should be noted that in the first scenario, the t-statistic of the absolute values shows that the difference of the means is not statistically significant but that the t-statistic of the differences of the values shows that the difference is significant. For the second scenario, both t-tests showed that the difference of the means is not statistically significant.

The computed vehicle travel time is for those vehicles that move in the same direction as the buses that have the ability to request priority. The comparison of the average travel time of vehicles in each scenario is shown in Figure 1(a) and 1(b). In Scenario 1, the reduction in vehicle travel time is estimated to be less than one-half

percent and for Scenario 2 about six percent, neither of which, based on the t-test analysis, proves to be statistically significant.

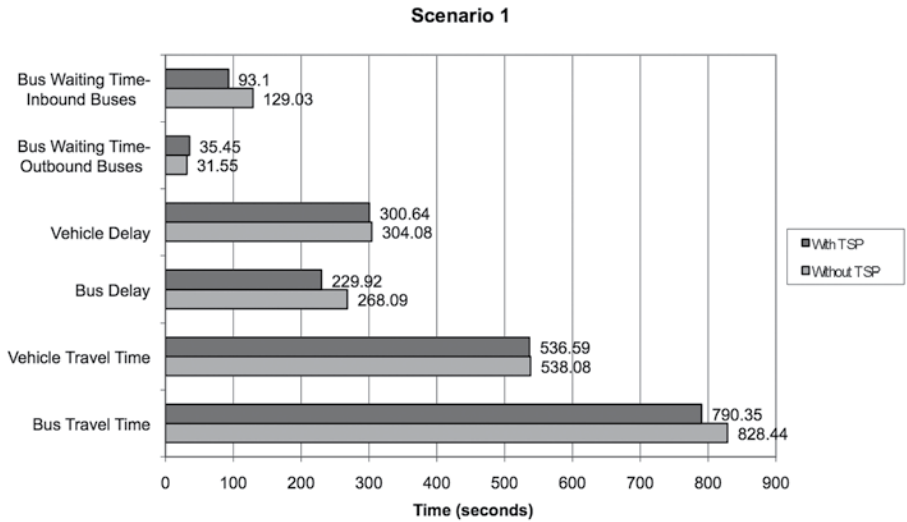
The values of bus delay for Scenario 1 and Scenario 2 with and without transit priority are shown in Figure 1(a) and 1(b), respectively. The results suggest that in Scenario 1 there is a 14.2 percent reduction of bus delay for buses with priority and a reduction of 16.5 percent in Scenario 2 when priority is provided. The t-test analysis shows that the difference of the average values for the first scenario is statistically significant and that the second scenario difference of the average values was not statistically significant. The t-test for the difference of the rates of change showed that the difference of the means is statistically significant.

The average vehicle delay computed for each scenario also is presented in Figure 1(a) and 1(b). The reduction in delay of the vehicles that travel in the same direction as the buses that get priority is about one percent in scenario 1 and about nine and one-half percent in the Scenario 2. In both scenarios, the statistical analysis showed that the differences of the means are not statistically significant.

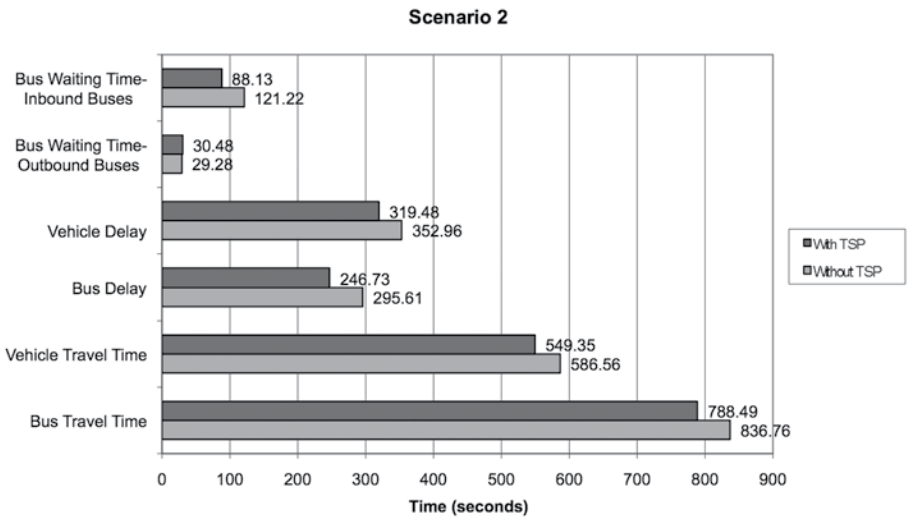
The outbound buses travel in the non-peak direction and do not get priority. The average bus waiting time outbound is shown in the Figure 1(a) and 1(b). In both scenarios, there appears to be an increase in the waiting time of the outbound line when priority is provided. This increase was about 12.4 percent for Scenario 1 and four percent for Scenario 2. For both scenarios, it was shown that these increases are not statistically significant.

As indicated here, the inbound line is in the peak direction and gets priority. The average waiting times of these buses are depicted in Figures 1(a) and 1(b). In Scenario 1, the reduction in the rate of change in the waiting time estimated is to be about 27.9 percent ; this reduction in Scenario 2 is about 27.3 percent. In both scenarios, the estimates are statistically significant.

Figure 2(a) presents the maximum queue lengths computed for Scenario 1. For Scenario 1, the change of queue length appears to be relatively small, ranging from a four and one-half percent increase to a seven percent decrease. The t-test shows that the differences are not statistically significant. The maximum queue lengths for Scenario 2 are presented in Figure 2(b). For Scenario, 2 the change fluctuates from a 19.7 percent increase to an approximately 2 percent decrease. The t-test here also shows that the difference is not significant.

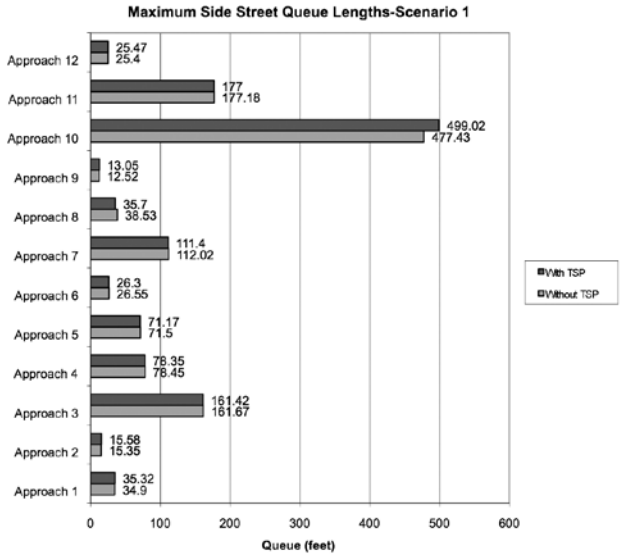


(a)

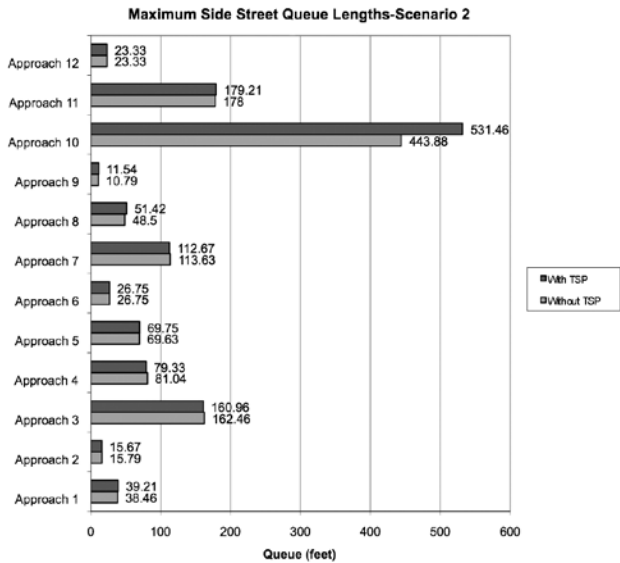


(b)

Figure 1. Evaluation Measures for Scenario 1 and Scenario 2 (in seconds)



(a)



(b)

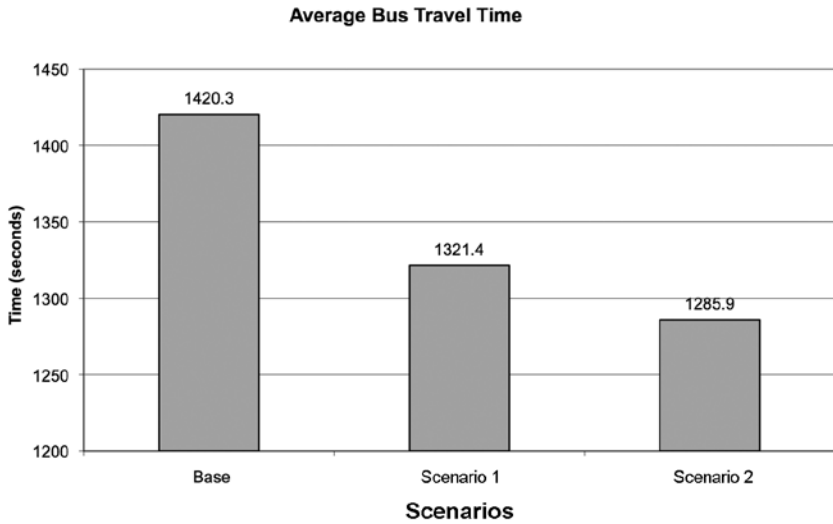
Figure 2. Maximum Side Street Queue Length (in feet) for Scenario 1 and Scenario 2

Old North Route. For the purpose of this research, two transit priority scenarios along the Old North Route were evaluated. One included a 10-second green extension for the AM buses traveling around the entire loop under existing schedules. Also for this corridor, only green extensions were considered because adding red truncation would create great disruption, which is not justified by the relatively low ridership. In the second scenario, it was assumed that all bus stops of the near-side type would be relocated to the farside, reflecting the notion that farside stop locations may reduce travel time. Two evaluation measures were employed in this simulation analysis: 1) travel time for the bus and 2) delay to non-transit vehicles.

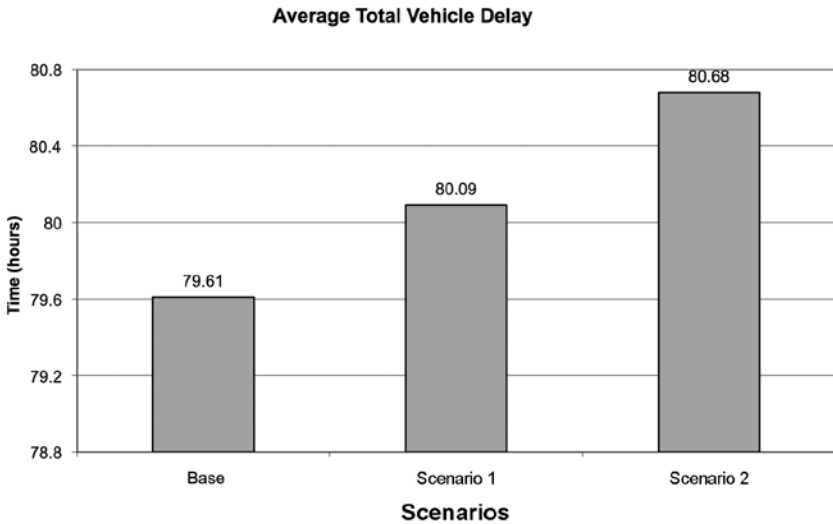
The average values for each evaluation measure were calculated based on 20 runs for each scenario. A statistical analysis using the Student's t-test was used to examine statistical significance. The results of the simulation analyses are summarized below. Further details are contained in Mermelstein (2007).

The average values of bus travel times to traverse the entire bus route are presented in Figure 3(a) for the base case (no priority) and the two scenarios. As can be observed, Scenario 1 shows a seven percent reduction in travel time, as compared to the base case and Scenario 2, which show an approximately two and one-half percent reduction, as compared to Scenario 1. The t-test analysis revealed that average travel times for the base and Scenario 1 are significantly different from each other, while the t-test did not show a statistically significant difference between travel times for Scenarios 1 and 2.

Figure 3(b) compares the average values of total delay for each scenario and the base case. There is a less than one percent decrease of total delay for other vehicles for Scenario 1 as compared to base scenario. There is a less than one percent decrease of total delay for other vehicles when comparing scenario 1 and scenario 2. Based on the t-test, the differences in delays to non-transit vehicles in the base case versus scenario 1 and scenario 2 versus scenario 1 were not statistically significant.



(a)



(b)

Figure 3. Average Bus Travel Times (in seconds) and Average Total Vehicle Delay (in hours) Along Old North Route

Simulation Results

From the simulation analyses, some preliminary conclusions can be drawn. The major results suggest that transit priority may aid in improving overall bus travel time along Route 15 and the Old North Route and that these results are generally consistent with the results reported in other TSP simulation analyses as well as before-and-after field studies. Also, there is no significant evidence that the 10-second green extension along Route 15 creates added waiting time delay to the buses that move along the opposite direction and do not get priority. Finally, there is no significant evidence that the 10-second green extensions along Route 15 and the Old North Route increases delay for the non-transit traffic along the side streets off Route 15 and the overall traffic on the Old North Route.

Guidelines

One of the objectives of this paper is the development of a set of guidelines to assist traffic engineers and transit planners in the planning and deployment of TSP strategies. In the analysis of transit priority concepts, transit priority is described as a form of traffic signal control strategy provided to facilitate the flow and passage of transit buses. Transit priority requests often are conditional and may, for example, be granted based on one or more conditions such as the absence of a pedestrian phase, the presence of a green interval, and a prescribed level of bus occupancy or degree of bus lateness. The guidelines are divided into two sections: 1) Planning, and 2) Deployment. These guidelines should be of interest to state and local traffic engineers and public transit planners and operators who are contemplating the implementation of a transit priority strategy.

Planning

Institutional Issues, Local Needs Assessment, and System Objectives and Requirements. Planning for a transit priority system is not a trivial task. A variety of institutional issues and local concerns must be addressed, ranging from the integration of transit priority into existing and potentially incompatible emergency vehicle preemption systems, to the identification of the important stakeholders, to the assessment of priority system needs and the formulation of local transit priority objectives and requirements (Collura et al. 2004; IBI 2006). These objectives and requirements provide the basis for an evaluation of transit priority strategies using either simulation models or field tests.

Pre-Deployment Impact Analysis. As part of planning, traffic engineers, transit planners, and other stakeholders should take steps to ensure that a local impact analysis is conducted to assess the anticipated consequences of alternative transit priority strategies under consideration. Among those consequences may be the impact on transit schedule adherence as well as impacts on traffic flow and vehicular and pedestrian safety. This local impact analysis may include field tests and/or the use of microscopic simulation analysis as presented before.

Based on a review of literature, the impacts of transit priority have been shown to have both positive and negative impacts in more than a dozen actual transit priority deployment projects in the U.S. and abroad. Moreover, simulation analyses reported in the literature review have produced results generally consistent with the impacts actually experienced in the project deployments.

Traffic Flow. There is significant evidence reported in TSP issues that the implementation of transit priority strategies may reduce travel times for transit vehicles. However, another expected impact may be delay to all other vehicles. Most transit priority projects have been deployed in the U.S. only within the past eight or nine years, and results from operational field test evaluations and simulation analyses are difficult to compare across the board because performance measures are not well defined in a standardized framework. Moreover, different transit priority strategies including green extensions only and green extension in combination with red truncation and other tactics, yield different impacts.

It should also be stressed that traffic simulation models may be a cost-effective means to analyze the impact of transit priority on traffic flow. As part of this research project, the VISSIM simulation model was used to assess impacts of a green-extension-only strategy on both transit and non-transit vehicles. Results indicated that bus service reliability could be improved, travel time would possibly diminish, and non-transit vehicle delay would likely be minimal. It also should be pointed out that the transit priority strategy might have a varying level of impact on transit and other vehicles. A green-time extension has also been determined by others to provide benefits to buses with no travel time impact to other users (Collura et al. 2004). However, a green extension in combination with red truncation (i.e., recall) may negatively impact non-transit vehicles, depending on the frequency of bus service. It is further recommended that a strategy consider the specific conditions that influence the corridor or area of interest. These conditions may include frequency and direction of travel for vehicles requesting priority, roadway characteristics, travel demand, presence and frequency of pedestrian

phases, transition strategy, cycle characteristics, and intersection spacing and progression strategy (Obenberger and Collura 1998). The use of different types of priority, such as queue jumping and phase re-servicing, in addition to green extension, may be necessary to match the status of the intersection in order not to affect signal coordination (Hood et al. 1995).

Safety for Pedestrians. Pedestrian fatalities typically account for more than 10 percent of motor vehicle deaths nationwide annually. In terms of accident locations, approximately one-third of accidents involving pedestrians have occurred at intersections (Zegeer and Seiderman 1994). It is suggested that a safety audit be conducted during the planning of transit priority systems, especially at locations near college campuses and in downtown areas. This audit should review the potential impacts that transit priority strategies might have on pedestrian safety. This audit should review the historical accident data within the area of interest, the length of pedestrian cycles based on the age and other demographics of the local population, the location of residential housing and retail activities, the location and placement of bus stops and pull-off areas, and the distance between bus stop locations.

Economic Analysis. It is strongly recommended that an economic analysis be performed prior to transit priority deployment to identify and estimate the fixed and recurring costs associated with priority investments. Recurring costs should include, for example, costs of an equipment maintenance agreement, as described below. ITS projects such as transit priority typically may have a short service life, lower upfront investment costs, and higher operating costs than traditional physical infrastructure projects. Since the cash flow profiles of ITS and traditional investments are radically different and the time value of money for ITS investments may not be that important, it has been argued that traditional benefit-cost analysis may not be appropriate and that a multi-criteria analysis approach should be used (Leviakangas and Lahesmaa 2002). It is suggested that life-cycle cost analysis be employed and an attempt be made to look at all life-cycle capital and operational costs within a larger economic analysis framework.

Financing. A financial plan for transit priority system deployment needs to be developed. This plan will identify funding sources to support capital investments and defray operating and maintenance costs. Funding is available from federal, state, and local sources, such as Congestion Management and Air Quality (CMAQ) and other programs in the SAFETEA-LU legislation of 2005. It should also

be stressed that such public funding sources may include transportation agencies as well as local fire and rescue departments.

Deployment

Procurement. While it has been suggested that transit priority systems can be procured using standard procurement processes, there are special considerations that need to be taken into account. Lessons learned from past ITS procurements and procurement experiences were used to provide insights into the identification of system objectives and requirements and preparation of requests for proposals and proposal evaluation.

Identification of Systems Objectives and Requirements. The procurement process begins with the identification of project objectives and requirements. As mentioned above, a clear understanding of the project scope of work objective is required of all stakeholders and participants to manage expectations and to preclude misunderstanding later in the process. Technological limitations also must be understood. A common frame of reference and a common definition of terms will need to be developed and adhered to. The proposed system objectives and requirements will then be translated into technical and operational requirements for vendors to develop into a fully-functional system. Sound technical specifications are a prerequisite for success. Vaguely-defined requirements will result in confusion and will necessitate negotiation with the contractor to settle differences.

RFP Preparation/Proposal Evaluation. A Request for Proposals (RFP) defines the project scope of work and system objectives and requirements, provides the technical and operational performance requirements, outlines the compliance requirements, and defines the performance period. It is suggested that a single integrator be responsible for design, procurement of components, system integration, installation, testing of the project, and user training.

Pre-Installation Site Survey. A pre-installation survey by the contractor(s) is highly recommended. As part of this on-site survey, the contractor should determine the impact of roadway geometry, bus stop placements, line of sight restrictions, pedestrian crossing volumes, and existing equipment to the system design. In addition, detector placement must be carefully sited to avoid putting a bus in a dilemma zone when the traffic signal turns amber. Detector placement and installation will need to consider the impacts of bus speed, length of green extension, and intersection width as well as the location of bus stops. For example, for

a bus traveling at 15 mph (22 fps) with a maximum green extension of 10 seconds through an intersection width of 40 ft, a detection distance of approximately 180 ft provides sufficient time to allow the bus to clear the dilemma zone.

System Installation. The typical priority system has three major subsystem components, including in-vehicle subsystems, roadside subsystems, and center subsystems. Each subsystem has its own installation challenges. In-vehicle subsystems consist of those component parts of the system that are installed on the vehicle. For example, a simple priority system may consist of the emitter and its power system and microprocessor system. More complex systems may include a vehicle location device such as a Global Positioning System (GPS) locator and Automatic Passenger Counters (APCs). Roadside subsystems are those parts of the system that reside outside the designated vehicles. Typically, they would include detectors mounted in the vicinity of the traffic signals and power sources that service the detectors, microprocessors, and communications equipment collocated with the traffic signal controller boxes. Center subsystems are those items of equipment that must interface with the central traffic signal management system and the transit management system.

It is recommended that the contractor be responsible for quality control throughout the installation process. The contractor should be required to provide installation drawings for approval. In addition, the contractor should be required to present a prototype installation of every subsystem and complete operational testing of all prototype installations. The contractor also should provide for review of site-specific installation specifications tailored to the physical characteristics of each site.

Evaluation. System evaluations during deployment provide a means to assess whether a priority system meets its intended objectives. The evaluation process should consist of the following elements: 1) an evaluation frame of reference, 2) evaluation planning, 3) evaluation implementation, and 4) potential evaluation spin-offs (Casey and Collura 1994).

The evaluation frame of reference provides a context for the evaluation. It defines the project objectives, external influences, local issues, and site characteristics. The evaluation plan outlines what should be measured (the impacts) and how impacts might be measured (measurement techniques). Evaluation implementation outlines evaluation plan execution, data collection, and analysis. For additional guidance on the design of ITS project evaluations, see the U.S. DOT's Joint Program Office website (2009).

A major product of the evaluation is an assessment of system objectives and impacts, including benefits, costs, and other consequences. Transit priority system objectives may relate to transit service reliability and efficiency and other traffic impacts. In addition, the priority system evaluation should consider assessing broader impacts related to interoperability, maintainability, reliability, expandability, affordability, institutional and organizational issues, and human factors.

An institutional issue where differences exist between planning and evaluating TSP strategies in small and medium-sized areas compared to large metropolitan areas relates to differences in staffing. Typically, there is limited staffing in small and medium-sized cities as compared to large metro areas. Thus, in small and medium-sized cities, it is important to attempt to keep the planning and evaluation of TSP alternatives simple and easy to carry out and to employ user-friendly simulation software (VISSIM) with relatively minimal data input requirements and data requirements.

Finally, it should be stressed that continuous evaluations should be conducted as soon as possible during deployment. Evaluations provide a means to measure the performance of the system against the measures used, and the results supply agencies in other metropolitan areas with useful information regarding deployment results, challenges, and lessons learned.

Summary, Conclusions and Recommendations

Innovations in traffic signal technology and other factors have increased the interest in TSP in small and medium-sized cities. The primary goal of this paper is to assist regional agencies and local jurisdictions in considering the use of traffic signal systems and technologies to implement TSP strategies for buses. The research includes an evaluation of the impacts, merits, and limitations associated with alternative TSP strategies and a review of the lessons learned in communities similar to those in Vermont where such strategies have been deployed. An underlying aim of the project is to assist transit planners and public agencies in planning and deploying signal priority strategies for transit buses in concert with other preferential signal treatments such as traffic signal preemption strategies. The coordination of TSP and preemption strategies for multiple types of vehicles is of utmost importance to preserve safety, facilitate emergency response, enhance traffic flow, and improve overall mobility.

The results of transit priority system deployments in the U.S. and abroad suggest that transit priority in small and medium-sized urban areas may reduce transit travel time and may lead to improvements in transit schedule adherence and other aspects of transit performance without major negative impacts on overall traffic flow. Also, the results of the preliminary simulation analyses suggest that transit priority may aid in improving overall bus travel time along Route 15 and the Old North Route and that these results are generally consistent with the results reported in other TSP simulation analyses as well as before-and-after field studies, as reported in the literature review. In addition, the simulation analyses suggest that there is no significant evidence that a 10-second green extension increases delay for the non-transit traffic along the streets intersecting Route 15 and the overall traffic on the Old North Route.

Finally, the guidelines developed should be employed by local jurisdictions, transportation agencies, and public safety agencies in the planning and design of transit priority strategies and treatments along signalized arterials.

An underlying aim of this paper is to recognize the differences in transit priority planning and deploying in small and medium-sized cities as compared to major metropolitan areas. The differences between planning and evaluating TSP strategies in small and medium-sized areas compared to large metropolitan areas relate to both technical and institutional issues. Technical issues have to do with data availability and transit usage. For example, typically in large metropolitan areas, input data required by simulation models such as VISSIM are readily available and, in fact, may be coded in Synchro files, which are easily accommodated by VISSIM. In small and medium-sized cities, such Synchro files may not be readily available and thus require field data collection, which was done in this research and described to guide transit planners in small and medium-sized cities.

Also, in small and medium-sized cities where transit ridership is relatively small as compared to automobile and other forms of travel, transit planners should be very selective, as in this research, in choosing the TSP strategy, e.g., green extension only. Planners in small and medium-sized areas also should be selective in choosing a small number of routes along which TSP may be appropriate, as opposed to in large metropolitan areas where there could be many more routes along which TSP (including a red truncation) might be considered.

An institutional issue relates to differences in staffing. Typically, there is limited staffing in small and medium-sized cities, compared to large metropolitan areas. Thus, in small and medium-sized cities, it is important to attempt to keep the

planning and evaluation of TSP alternatives simple and easy to carry out and to employ user-friendly simulation software (VISSIM) with relatively minimal data input requirements and data requirements.

Recommendations for future research:

- Carry out additional simulation analyses considering other priority strategies, including longer green extensions and multiple AM, PM, and mid-day peak analysis periods. As part of future simulation analyses, sensitivity analyses should be included considering different bus headways, bus stop types and locations, and fare collection methods.
- Conduct a small-scale transit priority field test in conjunction with the additional simulation analyses. As part of the field test, a set of transit priority objectives and evaluation criteria should be used to assess the performance of the priority system. These objectives and criteria should relate to bus service reliability, bus efficiency, and other impacts on non-transit traffic and overall traffic flow. As part of a transit priority field test, it is recommended that a contractor (e.g., the system/equipment vendor or a third party) be responsible for quality control throughout the system installation process. The contractor should be required to provide roadside equipment installation drawings for approval. In addition, the contractor should be required to present a prototype installation of each subsystem including roadside and in-vehicle components and complete operational testing of all prototype components as necessary. Finally, a maintenance agreement with a contractor should be established to deal with system/equipment challenges and malfunctions (if any) during the field test period.

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