Representation of Transit ITS in Network-Based Travel Models

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13. ABSTRACT

The increased use of Intelligent Transportation Systems (ITS) technology in public transit has two major impacts on travel forecasting. First, the technology will often result in an improved volume and quality of data that may be used for planning. Second, the technology may improve the performance of the transit system in a way that is visible to the traveler, thus traveler behavior will change.

This handbook presents the impacts of four widely deployed transit ITS technologies: advanced fleet management, transit signal priority, electronic fare collection, and improved traveler information. It suggests both short and long term improvements to the travel forecasting process.

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Acronyms

ADA	Americans with Disabilities Act
APC	Automatic Passenger Counter
APTS	Advanced Public Transportation Systems
ATIS	Advanced Traveler Information Services
AVL	Automatic Vehicle Location
BRT	Bus Rapid Transit
CAD	Computer Aided Dispatch
CATS	Chicago Area Transportation Study
CCTV	Closed-Circuit Television
CTPS	Central Transportation Planning Staff (Boston)
EFC	Electronic Fare Collection
FHWA	Federal Highway Administration
FTA	Federal Transit Administration
GIS	Geographic Information Systems
GPS	Global Positioning Satellite

HOV	High Occupancy Vehicle
IDAS	ITS Deployment Analysis System
IIA	Independence of Irrelevant Alternatives
ITS	Intelligent Transportation Systems
IVTT	In-Vehicle Travel Time
LACMTA	Los Angeles County Metropolitan Transportation Authority
LADOT	City of Los Angeles Department of Transportation
MBTA	Massachusetts Bay Transportation Authority
MDT	Mobile Data Terminal
MNL	Multinomial Logit
MPO	Metropolitan Planning Organization
MTA	Metropolitan Transportation Authority (New York)
NCHRP	National Cooperative Highway Research Program
OVTT	Out-of-Vehicle Travel Time
PDA	Personal Digital Assistant
PSRC	Puget Sound Regional Council
RTD	Regional Transit District (Denver)
TAZ	Transportation (or Traffic) Analysis Zone
TCQSM	Transit Capacity and Quality of Service Manual
TCRP	Transit Cooperative Research Program
TMC	Transportation Management Center
TMIP	Travel Model Improvement Program
TSP	Transit Signal Priority
U.S.DOT	United States Department of Transportation
VMS	Variable Message Sign

Executive Summary

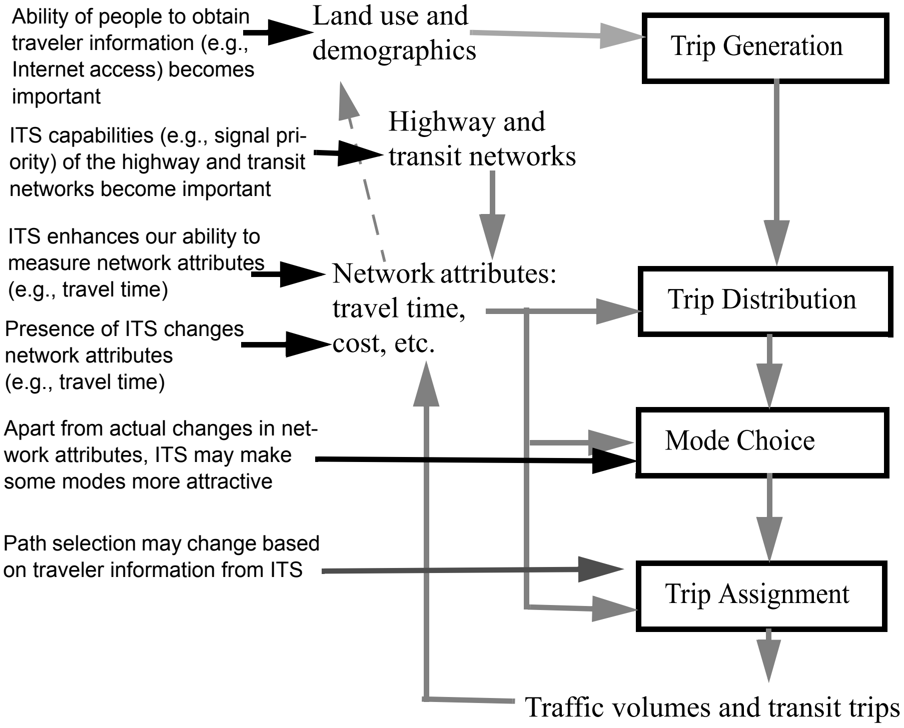
The use of Intelligent Transportation Systems (ITS) technology in new public transit investments, such as Bus Rapid Transit, has two major impacts on the planning process. First, the technology can provide new, better and more abundant data that may be used for planning. Second, the technology may improve the performance of the transit system in a way that is visible to the traveler, resulting in a change in traveler behavior and thus, ridership. Since an accurate projection of ridership is an important part of any assessment of a new public transit investment, it is important to consider the potential impacts of ITS.

The traditional process used by planning agencies to assess the impacts of a transportation system change involves four major steps:

- Trip generation, which first divides the analysis area into smaller transportation analysis zones, and then estimates the number of trips that will start and end in each zone.
- Trip distribution, which connects the trip ends.
- Mode choice, which allocates trips among various modes, such as single occupant auto, carpool, transit, and non-motorized.
- Assignment, which assigns the traffic to the appropriate routes in the transit and highway networks.

The existence of ITS Transit has impacts on all of these steps (Figure ES.1):

FIGURE ES.1 **ITS Impacts on the Four-Step Process**



Unfortunately, the standard four-step modeling environment presents significant challenges to the modeling of ITS impacts:

- Standard modeling often implicitly assumes that travelers have full and complete information on the options available to them. If an otherwise attractive option receives little use (and thus has a negative alternative specific constant in the demand model), this lack of use may be due to lack of traveler awareness. If an impact of improved traveler information is to improve traveler knowledge of the available options, there is no obvious way to determine the appropriate adjustment (if any) to model parameters.

- Standard modeling implicitly assumes a steady state level of service, with no unusual disruptions. However, major benefits of ITS include reducing the number of disruptions as seen by the traveler, keeping travelers better informed of disruptions, and quicker recovery from disruptions.
- Transit pathbuilding typically assumes travelers will choose one transit path from origin to destination or will choose among several paths via a simple rule (e.g., take the first vehicle to arrive). Improved real-time traveler information may, in some cases, enable more dynamic path choices.
- Accurate modeling of ITS often calls for a level of detail that is not present in traditional planning tools.

The next four sections focus on the impacts of four widely deployed transit ITS technologies: advanced fleet management, transit signal priority, electronic fare collection, and improved traveler information.

ES.1 Advanced Fleet Management

Commonly deployed elements of advanced fleet management include communications systems, automatic vehicle location (AVL), automatic passenger counters (APC) computer aided dispatch, service planning decision support and maintenance information systems.

Benefits from advanced fleet management generally occur via one of three mechanisms:

- Communications systems, automatic vehicle location and computer aided dispatch enable the transit provider to manage service in ***real-time*** to avoid gaps in service and enhance reliability.
- Automatic vehicle location, automatic passenger counters and service planning decision support systems provide improved data for ***service planning*** and for resolving customer complaints. Items typically include bus location at a given time, the exact time that a bus passes a timepoint, and passenger loading information. Improvements that may be made include schedule adjustments and redeployment of services to reduce overcrowding. Benefits include improved service reliability, improved comfort, and lower capital and operating cost.

- Maintenance monitoring and information systems provide data to enable improved vehicle ***maintenance.***

Implementation of advanced fleet management has been associated with an improvement in on-time performance of between 10 and 15%; however, this depends enormously on both the prior performance of the transit system (systems with poor prior performance have more potential for improvement), the number of deployed elements, and the effectiveness of the implementation. For example, the well-coordinated implementation of multiple elements might lead to an improvement in on-time performance from 80% to 90% (a 13% improvement).

The improvement in on-time performance will make the service more attractive to travelers, for the following reasons:

- Lower expected wait time. With random passenger arrivals, the expected wait time follows the formula $E(W) = \frac{H}{2} + \frac{Var(H)}{2H}$ where H is the headway (Osuna and Newell, 1972).
- Lower variance of wait time, leading to less likelihood of being excessively "late" at the destination. For randomly arriving passengers, the variance of the wait time (W) is given as $Var(W) = \frac{E(H^3)}{3H} - (E(W))^2$ (from Abkowitz et al., 1978, p 37). Decreasing the variability of wait and travel times is important to travelers who need to arrive at a destination at a particular time. In NCHRP Report 431 (1999) Small and others presented results from a stated preference survey of several thousand motorists along a corridor in California. They found that travelers place a substantial value on travel time reliability, with one minute of standard deviation of travel time having approximately the same value as two or three minutes of in-vehicle travel time.
- Greater opportunity for travelers to reduce their wait times further, by timing their arrivals with the vehicle arrival.

In all, the limited evidence suggests that a 10% improvement in on-time performance (say, from 80% to 88%) might be valued by travelers as highly as a 1 to 3 minute improvement in in-vehicle time.

ES.2 Transit Signal Priority

Transit signal priority (TSP) enables transit vehicles to move more quickly through signalized intersections. It provides a reduction in running time and thus traveler in-vehicle time. It may also provide a reduction in running time variability, thus leading to more reliable service. Three commonly used priority strategies include

- Signal optimization, where signal are timed to favor all vehicles, including transit vehicles, on the corridor.
- Red truncation (early green). When a transit vehicle is waiting at an intersection, the red time is shortened to reduce its wait time.
- Green time extension. When a transit vehicle is approaching an intersection and the green signal is about to turn red, the green time is extended so the transit vehicle may clear the intersection.

Under conditional priority schemes, a bus is given priority only if it is running late. Simulation results indicate that such conditional strategies may reduce the variability of running times by several percentage points. One study (Chang et al., 2003) indicated a 3 - 4% reduction in the standard deviation of trip time, while others (Muller and Furth, 2000; Gross 2003) indicated a larger improvement (20% reduction in standard deviation of trip time seen in Seattle).

Since TSP has a direct impact on in-vehicle time, its impact is conceptually easy to model. Both Furth (2004) and Lin (2002) have developed closed form equations to estimate the impact of signal priority on delay at a signalized intersection. Soo and others (2004) summarized travel time impacts from a number of deployment and simulation results. The Transit Capacity and Quality of Service Manual (Kittelson and Associates et al., 2003) indicates a 3 - 15 percent travel time savings from bus signal priority. For a 20-minute trip, this corresponds to an IVTT savings between 0.6 and 3 minutes.

The actual impact of TSP will vary greatly depending on how it is implemented:

- The type of strategy that is implemented (signal optimization, green extension, red truncation, other options)
- The conditions under which priority is given (unconditional versus conditional priority)
- The aggressiveness of the strategy (e.g., what is the upper bound on the green extension provided?)

- Frequency of bus stops and whether they are near-side or far-side. Near-side stops (where the bus stops before the intersection) are problematic because the signal priority system has no way of "knowing" how long the bus will remain at the stop.
- Current signal timings and whether the signals are part of a progression
- Major street and cross street volume/capacity ratios. A high volume/capacity ratio on the cross street will limit the amount of priority that should be provided to the major street.
- Street width and pedestrian activity. The minimum green time on the cross street may be constrained by the time required for pedestrians to cross the major street.

Therefore, great care is required in applying the observed or simulated benefits from one corridor in another corridor. At this point, typical practice is to use simulation to evaluate the benefits of a proposed TSP installation, and then use the results of the simulation to make adjustments to transit in-vehicle times.

ES.3 Electronic Fare Collection

Similar to AVL, electronic fare collection has both direct impacts and indirect benefits due to its archival capability. Direct impacts of cashless fare payment include less cash handling on vehicles and automated transfers. The electronic payment system may enable new fare policies. The archival capabilities of EFC systems may provide much better information on traveler origin-destination patterns.

Electronic fare collection (EFC) has often been accompanied by changes in fare policies. When changes in dwell time or ridership have been observed, they can generally be explained by the fare policy changes and not to the mere existence of EFC. For example, automated fare payment has sometimes been linked to a liberalization of transfer policies, with an increase in ridership resulting from the new transfer policies.

For pay-on-boarding situations, the use of EFC does not appear to significantly reduce dwell times. The Transit Capacity and Quality of Service Manual (Kittelson and Associates et al., 2003) indicates a passenger boarding service time of 4.2 seconds for swipe/dip cards, and 3 - 3.7 seconds for smart cards, times that are not substantially shorter than exact change fare payment.

Although the use of a new fare collection technology by itself may not have much impact on dwell times or attractiveness of transit, fare policies do have an important impact on both the supply and demand for transit service. On the supply side, a major determinant of dwell time (and thus in-vehicle time) is the number of doors that are used for boarding. A proof-of-payment system (with all doors available) will generally result in shorter dwell times than a pay-the-driver-on-boarding system. On the demand side, a policy of free transfers may lead to a significant increase in unlinked trips. Therefore, it is important to accurately model both the method of fare collection and the actual fare paid by riders.

The archival capabilities of electronic fare collection technology enables improved estimation of ridership patterns including linked trips. A fare payment card is typically encoded with a unique serial number that can be used to trace a passenger's path through the transit system. For example, if a passenger boards a bus and then transfers to a subway train, a record will be made of the route, time, and possibly location of the bus boarding and the transfer station for the subway.[1]

In addition to the new information on linked trips, electronic fare collection (like automated passenger counts) may also offer much larger sample sizes for passenger boardings than had been obtained previously with manual surveys. The new information provides immediate benefit to the transit agency service planning function, but also means that improved data on running time, reliability, and ridership will be available for use in planning models.

ES.4 Traveler Information

Traveler information is a complex area that includes pre-trip, at transit stop, and enroute information. Traveler information also encompasses several time frames, depending on how often the information changes:

- Several times per year (e.g., routes and schedules)
- Daily and hourly (e.g., major service disruptions)

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[1] Although the EFC system usually does not reveal where the traveler ***leaves*** the transit system, in New York City it was found that most riders begin a trip at the destination station for the previous trip (Barry et al., 2002). With this assumption, destinations can often be deduced on a system where multiple-trip fare cards are used.

- Minute-by-minute (e.g., arrival time for the next vehicle).

Basic route and schedule information has been available for years. In recent years, however, new ways to access this information have become available: automated phone systems, the Internet, and hand-held devices (Table ES.1). Another recent innovation is the deployment of automated trip planners. With an automated trip planner, the passenger gives an origin, destination, date of trip, and preferred departure or arrival time. The system then returns a suggested route or routes, along with estimated departure and arrival times.

TABLE ES.1 Examples of Static and Real-Time Information

Channel	Static (based on published schedules)	Real-Time (based on real-time system status)
Pre-Trip	Transit agency web site Itinerary planner	Web site with real-time vehicle location information.
In-Terminal / Wayside	Posted schedules and maps	Passenger information displays, monitors, automated sign boards to display arrival and/or departure times
In-Vehicle	Next stop announcements Destination signs	Information on connecting services
Personal Information Systems	Schedule downloaded onto personal digital assistant (PDA)	Notification via e-mail, pagers, etc.

Benefits of improved static traveler information include convenience (it is easier to find the information needed to make a trip) and, in some cases, total travel time (the information enables the traveler to find a better route).

Real-time information (either on the Internet or at transit vehicle stops) is an area that has generated intense interest and is seeing increasing deployments. Impacts of real-time information fall into three areas. First, it may make the wait for a transit vehicle less onerous by providing reassurance value and enabling the passenger to do other things during the wait. A survey of passengers using London Transport's COUNTDOWN system indicated a valuation of between $0.35 and $0.40. If the value of in-vehicle travel time (IVTT) is assumed to be $7 or $8 per hour, this valuation corresponds to approximately 3 minutes of IVTT.

Second, real-time information may enable more effective path selection through the transit system. This impact appears to be greatest under specific conditions:

- A passenger has multiple options available (For example, the choice might be either a 10-minute walk or a feeder bus with 10-minute headway and 5-minute travel time).
- There is a substantial difference in travel time among the options.
- There is a substantial and uncertain wait time for the options that have the shortest travel time. (In the above example, even with perfectly regular headways, the wait time for the feeder bus is anywhere between 0 and 10 minutes)
- Balancing the expected travel and wait time, the passenger who does not have real-time information is more-or-less indifferent among the options. (In the above example, the expected wait plus travel time for the feeder bus is 10 minutes, the same as the walk time.)

Without real-time information on the next arrival of the bus and assuming (for simplicity) that wait, walk and travel times are valued equally, the passenger would be indifferent between the two options, since each has an expected wait + travel time of 10 minutes. However, with real-time information, the passenger can decide to wait for the bus only if it is expected to arrive within 5 minutes. Under such a decision rule, the expected wait + travel time is approximately 8.6 minutes, a reduction of more than 1 minute.

Finally, real-time information may enable the transit agency to steer passengers away from an area that is experiencing a service disruption, and thus enable faster recovery from that disruption.

ES.5 Improving Current Practice in Modeling: What We Can Do Now

ITS Transit has a number of impacts that will influence traveler behavior. Some of these impacts, such as the impact of transit signal priority on in-vehicle time, can be captured immediately via better modeling of transit system performance. Others, such as improved service reliability from advanced fleet management, are more difficult to capture, given the current state of practice. This section discusses what can be done now, both in modeling and benefit-cost analysis, while section 6 outlines future improvements in both the use of data and in planning models.

ES.5.1 Using Base-year Travel Time Functions for Future Forecasts

In-vehicle travel time (IVTT) is a function of the speed, number of stops, and dwell time per stop for a transit vehicle. For buses, this is often computed as a fraction of automobile speed for a given link. The presence of transit signal priority changes this relationship between transit vehicle speed and automobile speed. Recommendations for improving current practice include the following:

- Ensure that the baseline calculation of transit IVTT is reasonably accurate, and is likely to remain accurate as conditions become more congested.[1] For example, a calculation that assumes transit speed is a fixed percentage of auto speed is likely to overstate bus travel times on slow, congested routes (The relative speed disadvantage of a bus becomes less as highway speeds are reduced) while understating bus travel times on routes where auto speed are high. Note that if changes to baseline calculations are made, it will be necessary to recalibrate and revalidate the model.
- Consider the impacts of signal priority, either through detailed simulation or at a minimum on an intersection-by-intersection basis. Prior research indicates that the travel time savings should be between 0% and 20%, and most likely under 10%.

ES.5.2 Capturing Other Benefits of ITS Transit

Other benefits of ITS Transit include improved service reliability (resulting in reduced variability of both wait and travel time), and improved “quality” of wait time resulting from real-time traveler information. Unlike the travel time benefit from signal priority (which is greater for longer trips), these other benefits primarily impact wait time; therefore, they should be viewed as occurring on a per-unlinked trip basis.

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[1] A long-range forecast may indicate significantly increased demand on a largely unchanged road network.

ES.5.2.1 Benefit Cost Analysis

In a benefit-cost analysis (where one is comparing transit without ITS for a set of travelers versus transit with ITS for the same set of travelers) it is possible to develop an approximate quantification of these benefits to existing travelers. This will help to indicate whether the investment in ITS is worthwhile.

Given the wide variety of ITS improvements that may be implemented and the wide variety of field conditions, it is impossible to develop a set of benefit values that may be simply "plugged in" to a benefit cost analysis. Rather, benefits should be developed based on careful analysis of the expected impacts of a specific planned implementation. That said, the discussion in prior sections of this paper indicates that the traveler benefit from the effective implementation of ITS Transit may be equivalent to several minutes of in-vehicle time.

ES.5.2.2 Network Planning Models

It is more difficult to incorporate service reliability and choice set impacts of ITS Transit into existing network planning models. The current structure of the vast majority of planning models (with their alternative specific constants and average travel/wait time coefficients) tends to mask other attributes of the transit option (such as service reliability) that are important to the traveler. As a result, the effects of these other attributes are captured elsewhere in the model, typically either in the alternative-specific constant or in the wait-time coefficient. Any effort to explicitly include these other attributes (for example, by adding a variable for wait time variability) will require that the model be recalibrated, because the addition of such a variable will result in changes to other coefficients.

ES.5.3 Ridership Impacts of Deployments

Many new transit investments, such as Bus Rapid Transit, combine multiple ITS elements with infrastructure improvements. Although it can be difficult to isolate the impact of the ITS elements, it is important to collect information on actual versus predicted ridership as these systems are deployed.

ES.6 Improving our Models in the Future

Recommendations fall into three areas. The first involves use of the data that ITS Transit provides. The second involves new data collection that will be needed to adequately capture the impacts of ITS Transit. The third involves improvements to forecasting models.

ES.6.1 Using the Data Provided

Two ITS Transit applications have the potential to significantly improve the quality and quantity of data available to planners: advanced fleet management and electronic fare collection.

ES.6.1.1 Advanced Fleet Management

By combining an archival and geographic information system capability with automatic vehicle location, improved information on transit running time and on-time performance will become available. With the addition of automatic passenger counters, improved information on passenger boardings, alightings and loadings will become available. This information can provide four benefits:

- On those roadway segments that are used by AVL-equipped vehicles, the location updates from those vehicles can be used to estimate travel speeds on those roadway segments for various time periods.
- Data will improve our understanding of run times and on-time adherence for transit.
- By examining AVL data from successive transit vehicles, we will improve our understanding of the actual headway distribution. This analysis, combined with the information on schedule adherence, will improve our ability to estimate actual passenger wait times. With the new information, it may be possible to develop and calibrate models that explicitly consider service reliability at the timepoint level.
- Automatic passenger counter data will improve our understanding of where vehicles are overcrowded, and which stops are most heavily used by passengers.

ES.6.1.2 Electronic Fare Collection

Archival data from EFC systems provides information on boardings at a great level of detail by time of day and day of week. This information is typically provided either at a station level (e.g., a subway system if off-vehicle fare payment) or at a route level (e.g., a bus where the EFC system has not been integrated with the AVL system). This can be used directly for transit service planning and to refine planning models.

Furthermore, by linking successive uses of the fare media and making some reasonable assumptions, linked trip information becomes available. This will assist in the calibration and validation of models.

ES.6.2 New Data Collection

The presence of ITS Transit suggests several areas where data collection should be changed in order to better assess the impact of ITS.

First, household travel surveys should ask whether households have high-speed, dial-up, or no internet access; whether household members have internet access at work or school; and whether household members regularly carry cell phones. They should ask about the usage of real-time traveler information.

Second, it may be beneficial to collect additional information on the highway network and on transit stops. Information might include the performance of signalized intersections, and real-time information availability, both for motorists and at transit stops.

Third, with a widely deployed AVL system, it will be possible to collect additional information on transit route running times, schedule adherence and headway variability.

Finally, with automatic passenger counters, it will be possible to collect information on actual passenger boardings and alightings.

ES.6.3 Model Improvements

Two gaps in current practice call for further research: service reliability and traveler information.

ES.6.3.1 Service Reliability

Demand models currently model the wait time as a linear function of the scheduled headway, with a possible cap on long headway routes. This approach masks the impacts of service reliability. In reality, there is a distribution of vehicle arrival times and headways that is based on both the published schedule and the reliability of the service. Passengers react to this distribution by either timing their arrivals in accordance with the schedule, or by arriving randomly. The combination of transit system performance and passenger behavior determines the distribution of wait times that passengers experience. Finally, the passenger disutility of waiting is a function of the distribution of wait time, where a passenger may well prefer a service with low wait time variability, even if it means a longer average wait. Restructuring our travel demand models to adequately capture the impacts of service reliability is a significant research effort Four initial steps are recommended:

- As mentioned earlier, ensure that deployed AVL systems have an archival capability, to provide data on schedule adherence.
- Out-of-vehicle time consists of several components including access time, first wait time, and transfer wait time. ITS may impact each of these components differently. Therefore, the effective modeling of ITS Transit calls for each component to be treated separately.
- Current best practice calls for a steeply increasing wait time penalty up to about 7 1/2 minutes of wait time, followed by a gradually increasing penalty. Sensitivity analysis with wait time should be performed with both the slopes of the two segments and the location of the breakpoint.
- Finally, in situations where reliability information is available, add a reliability term to the mode choice model, and assess both its significance and its effect on the other terms, such as wait time.

ES.6.3.2 Traveler Information

Assessing the impacts of traveler information may also call for a significant research effort. Most work in transit to date has focused on passenger attitudes and stated preferences. Four areas call for further research:

- When traveler information systems are deployed, carefully assess their accuracy and usability. Real-time vehicle arrival displays can have significant accuracy issues, either by missing vehicles entirely or by mis-estimating travel times.

Similarly, trip planners may be difficult to use and may not always provide the best routes.

- Ask travelers about their access to, and use of, traveler information.
- Assess whether traveler information is most valuable under routine conditions or under unusual conditions.
- Finally, develop and perform revealed preference experiments that assess whether travelers actually value the information that is provided. An example of such an experiment might be to place real-time information at selected bus stops along a route, and then assess whether passengers shift from the bus stops without real-time information to the bus stops with real-time information.

CHAPTER 1

Introduction

Many new transit investments today include one or more intelligent transportation system (ITS) components. Commonly used components include advanced fleet management with automatic vehicle location (AVL), transit signal priority, real-time traveler information, and electronic fare collection. The investments contemplated may be a stand-alone ITS investment, a New Starts baseline alternative,[1] or a major capital investment that includes an ITS component.

Beginning with a few experimental applications in the 1980s, many applications of ITS in transit are now seeing widespread use, thanks both to technological innovation and to support from Federal, State and local governments. Today, most new transit investments include at least one ITS component.

An accurate assessment of the new investment requires that the impacts of the ITS component be fairly evaluated, for the following reasons:

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[1] Defined as the “best that can be done” to improve transit service in a corridor without a major capital investment in new infrastructure (New Starts Guidance, 2003).

- First, it is much easier to consider the costs of ITS than the benefits. If the benefits in terms of service and ridership are not captured, there may actually be a negative incentive to include ITS in the alternatives.
- Second, the use of ITS can enhance the effectiveness of certain alternatives, thus making that alternative more desirable than it might otherwise be. Again, there may be the potential of changing the preferred alternative.

Unfortunately, the standard four-step (trip generation, trip distribution, mode choice, and assignment) modeling environment presents significant challenges to the modeling of ITS impacts:

- Standard modeling often implicitly assumes that travelers have full and complete information on the options available to them. If an option is not used (and thus has a high alternative specific constant in the demand model), this lack of use may be due to lack of traveler awareness. If an impact of improved traveler information is to improve traveler knowledge of the available options, there is no obvious way to determine the appropriate adjustment (if any) to model parameters.
- Standard modeling implicitly assumes a steady state level of service, with no unusual disruptions. However, major benefits of ITS include both reducing the number of disruptions as seen by the traveler, keeping travelers better informed of disruptions and quicker recovery from disruptions.
- Transit pathbuilding typically assumes travelers will choose one transit path from origin to destination or will choose among several paths via a simple rule (e.g. take the first vehicle to arrive). Improved real-time traveler information may, in some cases, enable more dynamic path choices.
- Accurate modeling of ITS usually requires a level of detail that is not present in traditional planning tools.

Because of these challenges, and because the four-step modeling process is still in widespread use, the ITS Joint Program Office has funded the research to produce this handbook. This handbook provides guidance for the incorporation of transit ITS improvements into traditional travel forecasting and simulation. It is intended to inform transportation professionals as to the likely ridership impacts of transit ITS improvements. It suggests reasonable values the impacts of transit ITS improvements. It suggests modeling and simulation procedures that may be used, and, in some cases, offers default values. It also indicates where further research and model improvements are needed to adequately address the impacts of transit ITS.

1.1 Intended Audience

The intended audience includes those transportation professionals who are charged with assessing the impacts of transit improvements. Users of the handbook may include employees and contractors of either a metropolitan or regional planning organization or a public transit provider. Some familiarity with the four-step modeling process and quantitative analysis techniques is assumed.

1.2 Organization

The executive summary discusses the methods for incorporating the transit ITS into planning models, and indicates the approximate impacts of each ITS improvement. There is also a brief discussion of the types of modeling that may be done to better assess the impact of each ITS technology.

Chapter 2 discusses the state of current planning practice. After briefly discussing how models are used, it reviews the modeling steps currently employed, including the following components:

- Transit network and centroid (traffic analysis zone) definition
- Transit access (links from centroids to transit)
- Modeled transit attributes, including line haul speed, stop delay and wait time.
- Transit path building
- Mode choice, with a particular focus given to discrete choice models, such as multinomial and nested logit. Factors (such as in-vehicle time, out of vehicle time) that are commonly included in models are reviewed.
- Transit assignment.

We review the few cases where the impacts of transit ITS have been incorporated into a planning model and discuss the interaction between simulation and four-step models. Finally, we review existing methods (often not model-based) for analyzing transit ITS improvements.

Chapter 3 discusses the potential impacts of transit ITS. Major impact areas are considered to be in-vehicle travel time, wait time/reliability, access time, convenience and cost. The ITS technologies of advanced fleet management, signal priority, electronic fare payment, improved traveler information, improved security and safety, and demand management were reviewed. Four technologies were identified as having both widespread deployment and a substantial potential impact on passenger mode choice. They are advanced fleet management, transit signal priority, improved traveler information, and electronic fare collection.

Chapters 4 through 7 review the four chosen technologies in more detail. Each chapter pertains to one ITS technology and is organized into six topics:

- A taxonomy of the area
- Impact linkages, from deployment of the technology to benefits
- Impacts of the technology on transit supply and demand
- An overall assessment of the impact of the technology on transit ridership
- Suggestions for incorporating the impacts of the technology into current planning and simulation models
- Areas for further research.

Chapter 8 presents some of the issues with projects that combine several ITS technologies, including empirical results from recent Bus Rapid Transit (BRT) implementations.

CHAPTER 2

State of Current Planning Practice

Transportation models are typically used to forecast future travel conditions and to assess the impacts of transportation system changes. A proposed transportation system change may have many impacts including

- Direct impacts on the transportation system, such as improved mobility and safety
- Economic impacts, including jobs and land redevelopment
- Impacts on the human environment, including possible disruptions to local communities
- Impacts on the natural environment, including air quality impacts.

A comprehensive transportation modeling system includes supply and demand models. Transportation supply models assess the performance of a portion of the transportation system. They may range from very simple (e.g., an equation that uses traffic signal timings and traffic volumes to assess the delay at the signal) to the complex (e.g., an integrated highway/transit simulation model). Transportation demand models predict how the system will be used. Aspects of usage include what trips will be taken, where will the trips go, what modes will be chosen, and what routes will be chosen. Accurate modeling of the impacts of a major transportation system change requires that supply and demand models work together.

Of particular interest to FTA is the use of models to evaluate new transit investments (New Starts). A New Starts evaluation includes both an evaluation of the investment itself and an evaluation of a baseline alternative, where the alternative is considered to be the “best that can be done” without the new investment.

This chapter focuses on the methods currently used by metropolitan planning organizations (MPOs) to represent the transit mode and ITS Transit in their planning models.

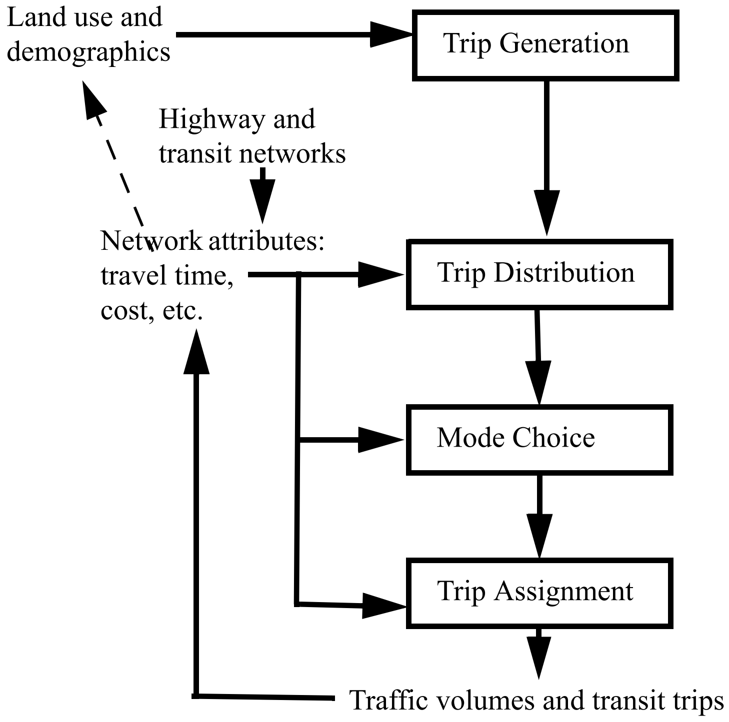
2.1 Four-Step Process

The framework traditionally used by planning agencies to assess the impacts of a transportation system change involves four major steps, hence its name. The steps are as follows:

1. Trip generation. After dividing the analysis area into smaller zones (often called transportation or traffic analysis zones), estimate the number of trips that will start and end in each zone.
2. Trip distribution. Connect the trip ends.
3. Mode choice. Allocate trips among various modes, such as single occupant auto, carpool, transit, and non-motorized.
4. Assignment. Assign the traffic to the appropriate routes in the transit and highway networks.

In the four-step process, the transit and highway systems are generally represented as networks. Users are modeled as flowing from an origin zone through the network to a destination zone. The supply attributes of the transportation system (travel time, cost) are captured as costs on the links.

FIGURE 2.1 **Four-Step Process**



2.1.1 Trip Generation

Since there may be millions of potential trip endpoints in a metropolitan area, it is impractical to model them individually. Therefore, the region is typically divided into transportation (or traffic) analysis zones, or TAZs. A metropolitan area may be divided into anywhere from hundreds to thousands of TAZs.

For each TAZ, trip productions and attractions are estimated. Trip productions are typically residences, and are based on the number of households, other land use attributes and household demographics. Trip attractions are typically places of employment, school or shopping.

Section A.2, “Transportation Analysis Zones (TAZs)” on page 178, contains more detail.

2.1.2 Trip Distribution

In trip distribution, the productions are linked with the attractions in order to form one or more trip tables. A trip table indicates the number of trips from each production to each attraction. This is generally done via a gravity model, where the number of trips between a pair of zones is inversely related to the distance between the zones. (e.g., for a home to work trip, a commuter is more likely to go to a workplace close to home than one that is far away).

2.1.3 Mode Choice

For each origin-destination pair in the trip table, mode choice compares the relative attractiveness of various transportation modes, and allocates trips accordingly. Modes typically include single occupant automobile, various carpool arrangements, public transportation (sometimes with walk and drive access to transit being treated as separate modes), and, in some models, non-motorized.

The attractiveness of each mode for each origin-destination pair is assessed via a pathbuilding process, where a trip is modeled on the highway or transit networks, and the resulting trip attributes are combined with demographic attributes and used as inputs to the mode choice process. Demographic attributes may include automobile availability and household income. Trip attributes typically include in-vehicle travel time, out-of-vehicle travel time, transit fare, and parking cost. Section A.3, “Transit Supply” on page 180 and section A.4, “Transit Demand” on page 192 contain further discussions of transit and mode choice modeling.

Time of Day Analysis

Although this is not a step in the traditional four step process, for some MPOs it does have implications for transit analysis mainly in the modeling of park and ride access. This step assigns trips to the period of day in which they occur (e.g. Peak A.M., Peak P.M., Night, Off-Peak, etc.), and it also decomposed park and ride trips into their component transit and auto trips. The purpose of decomposing these trips by mode and time of day is so that each can be assigned separately in the transit assignment step. One shortcoming of this step in the process is that it cannot estimate passenger shift from one time period to another time period due to the effects of congestion.

2.1.4 Trip Assignment

Trips are assigned to paths in the highway and transit networks. The outcome of this process is a set of traffic volumes on the highway links, and ridership volumes on the transit links. See section A.6, “Transit Assignment” on page 206, for further discussion of transit assignment.

2.1.5 Equilibration

The process described above is sequential. In reality, there are two important feedback loops. The first is that the trip times on a congested highway network may not be the same as the trip times that were assumed earlier in the modeling process. It is necessary to recompute trip distribution, mode choice and trip assignment using the congested times until an equilibrium is reached.

Second, in the long term, the transportation system has a significant effect on land use, and hence on trip generation. For example, both a new highway and a new transit station may serve as a catalyst for new development.

2.1.6 Four-Step Process and ITS Transit

Although detailed critique of the four-step process is beyond the scope of this report, it does present several challenges to the modeling of ITS:

- It is a sequential process, while in reality, there is considerable feedback. For example, as mentioned earlier the presence of transportation facilities may influence land use decisions.
- Models within the process consider a static, deterministic transportation system. For example, modeled travel times assume average conditions. Since ITS is often designed to address unusual conditions, this means that the standard 4-step process is at a level of detail inconsistent with ITS.

Nonetheless, some attempts have been made to consider the impacts of ITS Transit in the four-step process. The existence of ITS Transit has two major impacts on the modeling process

- ITS provides an opportunity for better, cheaper data collection and analysis.
- ITS may have impacts on transit system performance and traveler behavior.

2.2 ITS and Data Analysis

ITS Transit can potentially provide improved input data for conventional modeling. Archived automatic vehicle location (AVL) provides a more accurate picture of transit vehicle running times, and can provide information on transit service reliability. Archived automatic passenger counter (APC) data can provide accurate information on ridership, information that can later be used in model calibration and validation. See section 4.5.2, "Improving Current Practice" on page 84 for further discussion of the use of archival AVL data.

Electronic fare collection enables a transit operator to track where a particular fare card is used over the course of the day. This, with some inference, enables the collection of approximate origin-destination information for transit riders. See section 7.3, "Use of Archived EFC Data for Transit Planning " on page 151, for further discussion.

Other aspects of ITS, such as Geographic Information Systems (GIS), improve the modeling process by making it easier to use existing data. For example, the Los Angeles County Metropolitan Transportation Authority (LACMTA) uses a GIS application to help assess the benefits of implementing traveler information systems at potential stops. They have geo-coded their transit network (i.e. stops, routes, and stop amenities) as well as the passenger boarding volumes at each stop. This provides a visual representation of where the largest numbers of travelers are accessing the system. It also provides distances to nearby stops so that shifts in boardings to adjacent stops can be estimated and further analyzed. With information on the number of passengers using each boarding location, stop-level ITS improvements (such as reader boards) can be deployed to those locations where they will make the largest impact.

2.3 Impacts of ITS on Transit Supply and Demand

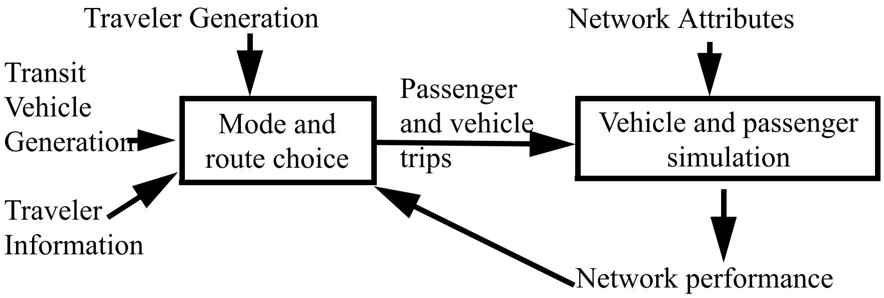
This section summarizes the different methods used by transit agencies and MPOs to analyze the impacts of transit ITS improvements on the transportation system. Understanding these impacts is vital for prioritizing improvements as well as for planning services after the improvements are in place. The information presented in this section was primarily gathered via interviews with transportation planning organizations in the United States (MPOs and transit agencies). These interviews were supplemented with available online documentation from the transportation agencies as well as any applicable technical reports or papers.

Typically, either simulation or transfer-of-benefits is used to estimate the impact of an ITS improvement. This impact is then incorporated into an existing regional planning model.

2.3.1 Simulation and Regional Planning Models

Simulation has been used for years to assess the performance of new rail systems. It is now seeing use in ITS applications, where simulation is used to assess supply parameters, such as travel times, in the presence of ITS. These supply parameters then become inputs to the regional planning model, which is used to determine mode and route choice. Figure 2.2 shows the general framework.

FIGURE 2.2 **Integration of Simulation and Regional Planning**



The regional planning model provides base case or input data, such as mode split and trip information, to the simulation. The simulation then analyzes the changes in the transportation network due to the ITS benefit(s). The results of the simulation are estimates for parameter values (i.e., travel times) that can be fed back into the regional planning model. While this method can provide good estimates of the impacts of an ITS project, it is important to maintain consistency between the assumptions and data used in the two models. Examples of using simulation to incorporate the impacts of ITS into a regional planning model include the following:

DYNASMART

Abdelghany and Mahmassani (2001) presented a framework for integrating trip assignment and simulation for intermodal networks. Their model includes the following components:

- Travelers with trip starting time, origin, destination, and car ownership status
- Transit vehicle routes and schedules
- Prevailing travel times on each link (estimated with simulation)
- A mode-route choice module that is run once every few minutes (dynamic traffic assignment and mode choice). This module uses a shortest path algorithm to determine several origin-destination paths based on various objectives, such as travel time and cost.
- Simulation of vehicle movements

Abdelghany, Abdelghany, Mahmassani and Abdelfatah (2001) presented an application of the above framework to the evaluation of various bus preemption (signal priority) strategies at signalized intersections. Preemption strategies considered included green extension and red truncation.

More recently, Abdelghany, Abdelghany and Mahmassani (2004) modeled a hypothetical bus rapid transit (BRT) service. Supply characteristics of the service included exclusive right-of-way lanes, limited stops, signal prioritization and reduced boarding times. The model considered both the supply characteristics and mode choice.

Central Transportation Planning Staff (Boston)

Boston's MPO (Central Transportation Planning Staff) and their consultants used a regional planning model in conjunction with an intersection-level model for the Urban Ring Project. The Urban Ring is a 15-mile corridor starting at Logan Airport and continuing around Boston through industrial areas, business districts and densely populated neighborhoods located 1 to 4 miles from the downtown area. This project incorporates a significant number of ITS improvements such as traffic signal priority, traveler information reader boards, automatic vehicle locations system, and electronic fare collection.

CTPS provided current trip and mode split data from their regional planning model to the consultants who then used a intersection-level analysis to determine changes in travel times and air quality. These changes were fed back into the regional planning model in order to further refine estimates of benefits.

PRUEVIIN (Seattle)

As part of the Metropolitan Model Deployment Initiative, Mitretek analyzed the impacts of various (primarily highway-related) ITS improvements in the Seattle area (Wunderlich, Bunch and Larkin, 1999). The methodology, called the Process for Regional Understanding and EValuation of Integrated ITS Networks (PRUEVIIN), incorporates a planning model and traffic simulation to capture ITS impacts under various scenarios.

Since ITS is thought to have a greater benefit under unusual conditions, one notable aspect of this approach was the use of scenarios to represent the application of ITS under non-average conditions. Scenarios represented either a reduction in capacity (due to incidents or bad weather) or a change in demand (Figure 2.3).

FIGURE 2.3 **Scenario Framework**

	Low Demand	**Average Demand**	**High Demand**
Major incident(s) or construction	Weekend construction		Major crash during rush hour
No major incidents good weather		“Average” conditions	Special event
Bad weather		Snowstorm	

Thirty scenarios were drawn from an analysis of traffic flow data, weather and historical incidents. Travel time impacts for each scenario were then rolled into an annual average. By comparing this average with baseline travel in the regional planning model, potential shifts in travel patterns can be assessed.

ITS deployments that were analyzed fell in the areas advanced traveler information, advanced traffic management, and incident management. Not surprisingly, the greatest benefits for advanced traveler information systems were found during extreme conditions (heavy demand, bad weather, or major incidents).

2.3.2 Transfer-of-Benefits

This method involves transferring estimated or observed benefits from a particular ITS implementation in another metropolitan area (i.e. Ridership in city X increased by 10% with the implementation of advanced fleet management, therefore our ridership will also increase by 10%). With some ITS improvements such as transit signal priority and AVL, benefits are fairly well documented, and it is sometimes possible to extrapolate these benefits from one metropolitan area to another. It is important for the metropolitan areas to have similar transit networks and transit user demographics. Databases of observed benefits to various cities (such as the IDAS benefit database) are useful in this respect as they provide multiple examples and ranges of benefits values for a particular ITS improvement. These observed data points should however only be used as rough estimates, because an ITS improvement is often accompanied by other changes in a transit network, and these changes could also be responsible for the "observed benefits" attributed to an ITS improvement. For example, it is quite common for a change in fare policy to accompany the implementation of an electronic fare collection system. This change in fare policy may result in a fare reduction for many trips. Therefore, careful analysis is required to determine the actual impact of the electronic fare collection system versus the change in fare policy. (See, for example, Carfiero’s 2002 TRB presentation, "The Effect of Fare Policy Changes on Ridership at MTA New York City Transit.”). Examples of the use of transfer-of-benefits include the following:

San Francisco Municipal Railway (Muni)

In the San Francisco Municipal Railway Draft Amendment to Short Range Transit Plan FY 2001-2002, Muni assumed a 5% ridership increase from the use of real-time passenger information. This increase was justified by stating that:

> "The consultants analyzed the effects of real-time passenger information systems on ridership levels and found a 5% increase attributable to the presence of such a system on a line. This estimate is based on data from several European peers, where ridership gains of about 5% have been found in several applications that are comparable to San Francisco."

North Texas Council of Governments MPO

To model transit signal priority, this MPO reduced the roadway link times for transit vehicles by a percentage typical for TSP systems.

Chicago Area Transportation Study (CATS) MPO

CATS used the ITS Deployment Analysis System (IDAS) to generate ideas for modeling ITS improvements in their existing planning model. The benefits database and default parameter values in IDAS provide a framework for incorporating various ITS impacts.

2.3.3 Perceived Gaps in Existing Methods

While some of the methods discussed are more rigorous than others, all of the methods have weaknesses. The outline below summarizes the major gaps in each method.

a) Regional Planning Models - The main gap in this method is that the impacts of some ITS components are not easily incorporated into the existing planning model. For example, the effects of traveler information systems on transit travel times and traveler perceptions of travel times are not well understood.

b) Stand-Alone Models - While micro simulations and GIS applications are very powerful, there is a potential for inconsistencies to arise in the assumptions used in the planning models and these applications.

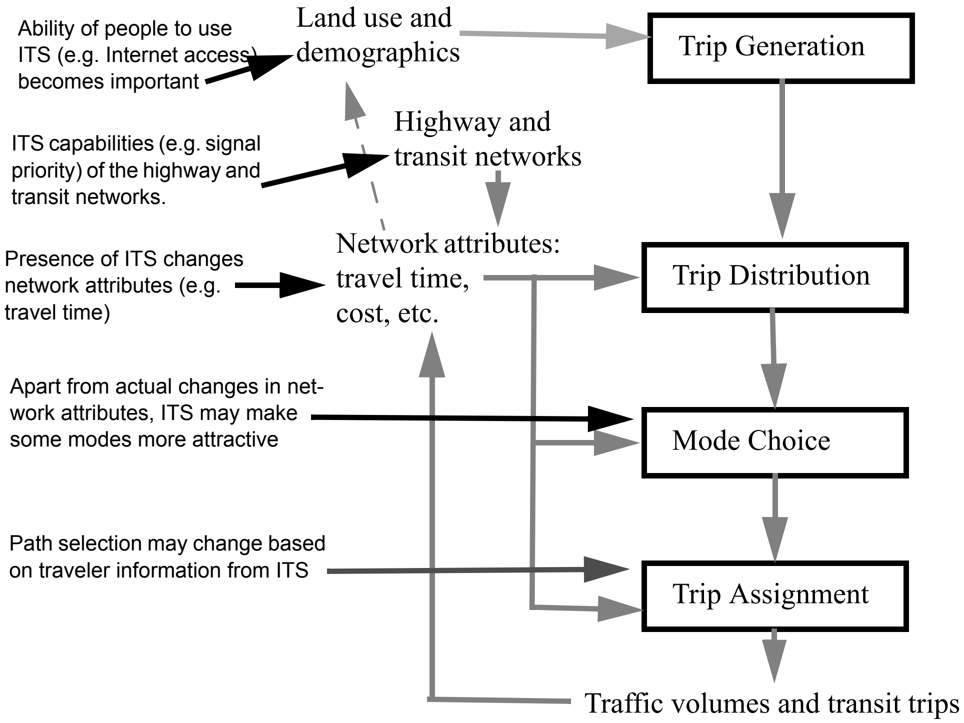
c) Transfer of Benefits - A challenge is finding an analogous situation (city, corridor, technology, etc.) whose benefits are both well documented and transferable.

A challenge from the Federal perspective is that since each agency may evaluate an ITS investment in a different way, there is no reasonable basis for comparing the impacts of ITS investments across agencies.

2.4 Summary and Remaining Issues

As can be seen in Figure 2.4, ITS Transit can have a number of impacts on the four-step process.

FIGURE 2.4 **ITS Impacts on the Four-Step Process**



Three major issues with the incorporating of ITS Transit into current planning models are

- the need to revalidate a model when adjustments are made
- the need for additional data collection
- that current planning models are not well suited to capturing some impacts.

2.4.1 Revalidation

The current structure of the vast majority of planning models (with their alternative specific constants and average travel/wait time coefficients) tends to mask other attributes of the transit option (such as service reliability) that are important to the traveler. As a result, the effects of these other attributes are captured elsewhere in the model, typically either in the alternative-specific constant or in the wait-time coefficient. Any effort to explicitly include these other attributes (for example, by adding a variable for wait time variability) will require that the model be recalibrated and revalidated, because the addition of such a variable will result in changes to other coefficients.

2.4.2 Additional Data Collection

Proper assessment of the impacts of ITS Transit may require additional data collection, both on the supply side and the demand side. One example of data collection on the supply side may be traffic signal information...are signals on a corridor coordinated? do they support transit signal priority? Another example may be the reliability of travel times, since a major benefit from ITS Transit may be improved service reliability and not simply a reduction in average travel time. An example of added data collection on the demand side includes additional information on household or workplace demographics. Do people have cell phones? Do they have high-speed Internet access at home? at work? This information will aid in the assessment of the potential effectiveness of traveler information strategies that use cell phones or Internet.

2.4.3 Impacts Are Not Captured

Planning models, by and large, deal with average conditions. Modeled travel times and fares are generally averages. An ITS improvement that affects one of these averages (for example, transit signal priority reducing the average in vehicle travel time) is conceptually easy to model.

Other impacts (such as an improvement in service reliability) are conceptually harder to model in the existing framework. As a result they are generally not modeled and their impacts may be buried in either the wait time coefficient (See discussion in Chapter 4) or the alternative specific constant.

CHAPTER 3

Potential Impacts of ITS Transit

This chapter outlines the expected impacts of intelligent transportation system (ITS) technologies on the demand for transit. In it, we identify the most promising transit ITS technologies and summarize their impacts on the factors that affect demand for transit.

3.1 Framework of ITS Impacts

The impact of ITS Transit on passenger behavior is not direct. Rather, there is a chain of impacts,[1] from deployment of the system to changes in passenger behavior (Figure 3.1). Each block of this chain is described below.

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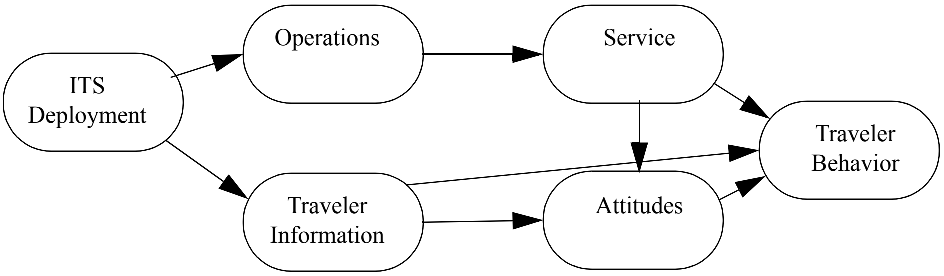
[1] This chain of impacts presented here is taken from the FTA-sponsored Transit ITS on Traveler Behavior project (2004).

FIGURE 3.1 **High Level ITS Impact Linkages**



3.1.1 ITS Deployment

This block describes the ITS elements that may potentially have an impact on passenger behavior, either via an impact on transit operations, or by supplying information directly to the passenger. Examples of ITS deployments include

- Fleet Management (includes advanced communications for operations, automatic vehicle location, automatic passenger counters, operations and service planning decision support, and maintenance systems)
- Transit Signal Priority
- Transit Security and Safety
- Traveler Information (includes static information such as posted schedules as well as real-time information)
- Electronic Fare Collection
- Transportation Demand Management

3.1.2 Operations

The implementation of ITS technology may result in operational changes. These are changes to the transit operation as seen by the transit agency. They are grouped into the categories of fleet management, service customization, service planning, security and safety, and fare collection. Examples of operational changes include the following:

- Fleet Management (includes frequency of service, travel time, travel time reliability, and seat availability)

- Service Customization
- Service Planning (includes route shifts in response to changed markets, schedule adjustments and route adaptation in response to short term events)
- Security (from crime) and Safety (from accidents)
- Fare Collection (includes payment options, impact of the fare collection method on vehicle dwell time, and evasion rates)

3.1.3 Traveler Information

The ITS technology may be primarily focused on providing travelers with improved information, and not on operational changes to the transit system. A typology of traveler information includes the following elements:

- Static information (includes published and posted schedules, trip planners, and fare information)
- Real-time information (includes service disruption and time until next vehicle information)

3.1.4 Service

These are the attributes of the transit service as seen by the passenger. Major service attributes include the following:

- Total in-vehicle time (IVTT)
- Access and egress time
- Waiting time at stops
- Number of transfers
- Waiting time for transferring
- Walking time for transferring
- Service reliability (both waiting and in-vehicle time)
- Early/late departure/arrival time relative to desired departure/arrival
- Convenience
- Safety/Security
- Cost

Convenience is a catchall term that includes many factors:

- Can the passenger find out about services easily?
- Once at the terminal, does the passenger know where to wait?
- Is the passenger informed of his or her waiting time?
- Is fare payment convenient?
- Is a seat available on the vehicle?
- Are the vehicles and waiting areas clean?
- While enroute, is the passenger informed of trip status?

The importance of the various attributes was summarized in TCRP 27 (Charles River Associates, 1997):

- Travel time is important.
- However, not all time savings are equal. Wait time is the most important of all, followed by access/egress time, and then in-vehicle travel time.
- Prices do influence choice, but demand for transit is inelastic with respect to price. This means that if the price of transit is increased by x%, demand will drop, but by less than x%.
- Comfort and convenience are very important (but difficult to represent).

One consequence of the importance of both wait time and convenience is that an excessive number of transfers are highly undesirable. Few passengers are willing to transfer more than once.

3.1.5 Attitudes

Attitudes towards public transit may have a significant influence on usage. In turn, the performance of the transit system, may, over the long term, have an influence on attitudes towards it.

3.1.6 Traveler Behavior

Long term behavioral changes include auto ownership decisions, work location, home location and employment status. Short term travel behavior changes include trip chaining (the number of destinations that are chained together in one journey, trip frequency, destination, departure time, mode choice (both access and line haul modes), and route choice for both access and line haul modes.

3.1.7 Summary

Table 3.1 summarizes the potential impacts of various ITS Transit technologies.

TABLE 3.1 Potential Impacts of ITS Transit

Technology	IVTT	Wait Time	Access Time	Reliability	Convenience	Cost
OPERATIONS ORIENTED						
Fleet Management						
Communications Systems	+	++		++		+
Automatic Vehicle Location	+	++		++		+
Automatic Passenger Counters				+		+
Operations Decision Support	+	+		+		
Service Planning Decision Support	+	+	+	++		+
Maintenance Systems	+	++		++		+
Transit Signal Priority	++	+		+		+
Intelligent Vehicle Initiative						+
Transit Security and Safety						
On-Vehicle Surveillance	+[a]				+	+
Station/Facility Surveillance		+[b]			+	+
Incident Response	+	+		+		
CUSTOMER/DEMAND ORIENTED						
Traveler Information						
Static Information	+	+	+		+	+
Real-time Information	+	+		+	+	
Electronic Fare Collection	+				+	+
Transportation Demand Management						
Dynamic Ridesharing			+		+	+
Automated Service Coordination			+	+	+	
Station Cars and Access Support			+		+	
Pedestrian ITS			+		+	
Parking Management			+		+	
Multimodal Transportation Management Centers						+

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[a] A more secure on-board environment may reduce the disutility of in-vehicle time

b. A more secure waiting area may reduce the disutility of wait time

Although the traditional “four-step” process for travel-demand forecasting involves trip generation, trip distribution, mode choice, and assignment, this chapter is primarily focused on the mode choice and transit path assignment elements of this process. However, ITS Transit may produce several other benefits that are not discussed here:

- Long-term impacts on trip generation and distribution
- Direct cost savings to the transit operator, for example, through the use of automatic vehicle location (AVL) and automatic passenger counters (APC) to better target service changes
- Improvements in transit employee safety and satisfaction, thus reducing turnover
- Use of transit vehicles as probes in a highway ITS initiative, thus improving the quality of information provided to all travelers.

3.2 ITS Technologies

We will next review various ITS technologies, to examine how they will impact demand for transit service. For each technology we discuss four areas:

1. Area of impact. Does it affect the transit operator’s ability to supply service, the passenger’s comfort and convenience, or the passenger’s ability to effectively use transit?
2. Specific service attributes that are impacted.
3. Magnitude of the impact, if known.
4. Usage of the technology, including, where available, the number of existing or planned deployments in the United States as of 2000.

Based on areas 3 and 4 we will recommend technologies for further investigation and evaluation. We have broken the technologies into six categories:

- Fleet Management
- Transit Signal Priority

- Electronic Fare Collection
- Traveler Information
- Transit Safety and Security
- Transportation Demand Management.

3.2.1 Fleet Management

Examples of fleet management technologies and their impacts are listed in Table 3.2, and are discussed below. These systems primarily affect the transit operator's ability to supply service, either by helping to assure adequate physical condition of the fleet (maintenance information), or by assisting with fleet operations.

TABLE 3.2 Fleet Management Impacts

Fleet Management	Description	Service Impacts
Communications Systems	Enabling ITS that is required to implement other services. Provides necessary connections and band-width for information flows to/from vehicles, wayside devices, operations center(s), and other agencies	- Improved service reliability
Automatic Vehicle Location	Enabling ITS that is required to implement other services. Provides location tracking for vehicles, equipment, and potentially personnel.	- Improved service reliability
Automatic Passenger Counters (APC)	Automated counting of passengers ons and offs.	- Increased comfort (re-allocate service to lessen overcrowding)
Transit Operations Decision Support	Tracks location and performance of vehicles (in-service and support) and provides decision support for real time fleet operations.	- Improved service reliability
Service and System Planning Decision Support	Turning data into useful information that can be used to improve operations	- Improved service reliability - Increased comfort (re-allocate service to lessen overcrowding)
Maintenance Information Systems	Maintenance operations support	- Improved service reliability - Increased comfort

Communications Systems

Improved communications between vehicle driver and dispatcher enhances reliability, safety, and security. With good communications, service disruptions can be more effectively addressed. This improves reliability and may reduce wait times. If the transit vehicle is involved in an accident, a quicker response may be possible. Real-time communications may also act as a crime deterrent. Depending on the perceptions of crime within the system, the improved security may make the transit system more attractive.

According to *Advanced Public Transportation Systems Deployment in the United States, Year 2000 Update* (Casey, 2002), communications systems are widely used, with over 300 operational or planned deployments in the United States. Their primary impact is on transit operator operations, which can become more efficient with reduced voice communications. Impacts on demand for transit are indirect and have not been quantified.

Automatic Vehicle Location

Automatic vehicle location (AVL) systems enable other improvements that may impact demand. AVL provides real-time knowledge of vehicle location, and therefore enables the provision of next-vehicle-arrival information to passengers. AVL can also provide an accurate record of vehicle on-time performance, thus enabling the creation of schedules that better reflect actual conditions.

AVL systems are in widespread use with over 200 existing or planned deployments in the United States. APCs are somewhat less widespread, with approximately 100 existing or planned deployments (Casey, 2002).

AVL systems enable the transit agency to provide a more reliable service, both by providing more accurate run time data for service planning, and by enabling the operator to know where vehicles are at all times. The Transit ITS Impacts Matrix[2] indicates that several agencies have reported a substantial (10-20%) improvement in on-time performance with the use of AVL systems. This improvement was coupled with a significant (24%) reduction in customer complaints. Therefore the effective use of AVL may have a significant, if indirect, impact on demand. Both Denver and Milwaukee have attributed 5% increases in ridership to AVL. However, Toronto has more conservatively estimated that AVL would only result in a 0.5 – 1% increase in ridership.

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[2] A website (http://web.mitretek.org/its/aptsmatrix.nsf) sponsored by FTA that is intended to be a resource for obtaining the impacts of transit ITS technologies. For this report, this matrix was accessed at various times in 2003.

For a given transit route, the impact of AVL on demand depends strongly on two factors:

- how poorly the route is performing now (is there substantial room for improvement?), and,
- whether the transit operator will be able to effectively use the AVL system to improve service reliability.

Automatic Passenger Counters

Automatic Passenger Counters (APC) enable improvements to the service planning process, by providing a large amount of boarding and alighting information. The accurate passenger counts from APC enable services to be better targeted to relieve overcrowding.

Transit Operations Decision Support

This is sometimes called computer aided dispatch (CAD). The use of some form of automated software is widespread, with over 300 existing or planned deployments in the United States (Casey, 2002). Impacts have not been quantified, but include use of the data for better service planning.

Service and System Planning Decision Support

Examples of systems to support service planning include geographic information systems (GIS), analysis of archived ITS information, and advanced scheduling and runcutting software. By analyzing AVL and APC information, transit agencies can make service adjustments that improve on-time performance (by adding time to schedules for route segments that are consistently late), improve productivity (by tightening schedules that are consistently early, and reducing underutilized services) and relieve overcrowding by increasing services on routes that are overutilized.

Maintenance Information Systems

Maintenance Information Systems are defined in the Transit ITS Impacts Matrix as follows:

> "Automatically monitors the condition of transit vehicle engine components and provides warnings if failures occur. Software that manages the maintenance records of transit vehicles."

The systems see moderate usage, with over 100 existing or planned deployments (Casey, 2002).

Impacts have not been quantified but, given the importance of service reliability to passengers, could be significant. Potential impacts include improved service reliability via fewer road calls.

3.2.2 Signal Priority

By reducing delay for buses, signal priority has a direct impact on in-vehicle travel time. Depending on how it is implemented, it may also have an impact on service reliability, thus reducing wait times (Table 3.3)

Eighty-eight existing or planned deployments of signal priority are reported (Casey, 2002). Most impact assessments have focused on in-vehicle travel time improvements, and not on service reliability.

The Transit ITS Impacts Matrix indicates that signal priority has resulted in signal delay reductions of 10 – 50%, with 5 – 40% reductions in bus travel time. Most of these travel time reductions were in the 10% range.

TABLE 3.3 **Transit Signal Priority Impacts**

Description	**Impacts**
Giving transit vehicles priority over other vehicles at signalized intersections. The TSP impacts and costs depend upon the type of TSP and how it is combined with Running Way Priority Strategies.	- Lower in-vehicle travel time - Improved service reliability

3.2.3 Electronic Fare Payment

Electronic fare payment is in widespread use, particularly in the largest metropolitan areas. There are close to 200 existing or planned deployments in the United States (Casey, 2002). Major impacts (Table 3.4) include convenience and possibly in-vehicle travel time. These impacts depend heavily on the difficulty in using existing systems, and whether the introduction of electronic fare payment is accompanied by a change in fare policies.

TABLE 3.4 **Electronic Fare Collection Impacts**

Description	Impacts
Cashless payment of fares, parking, and other fees. Benefits and costs of systems will be determined by media type, integration, and services covered	- Convenience - Cost (if accompanied by change in fare policy) - Travel time (if dwell times are reduced)

Four ways in which an existing fare payment system may be difficult to use have been identified:

- A requirement for exact change. Here, the difficulty depends on both the fare being charged and whether dollar bills are accepted. For example, a 95-cent fare is more awkward than a $1.00 fare.
- A requirement for advance purchase of tickets or tokens, especially if there are a limited number of advance purchase locations.
- A multitude of service providers, with separate fare payment systems.
- A burden on vehicle operators (for example, not requiring exact change on a bus). Such a burden lengthens the boarding process, increases dwell time, and thus increases in-vehicle travel time.

An example of a change in fare policies is the introduction of free transfers. Another example is the introduction of discounted fares, such as receiving $11 worth of trips from the purchase of a $10 fare card.

Even though one transit operator (Chicago Transit Authority) is reported in the Transit ITS Impacts Matrix as estimating a 2 – 5% increase due to electronic fare payment, the actual increase in ridership is heavily dependent on both existing fare collection practices at the operator in question and on whether the introduction of electronic fare payment is also accompanied by a change in fare policies.

3.2.4 Traveler Information

Traveler information is a complex area. Issues include the type of information supplied, where in the journey it is supplied, its accuracy, and what passengers are able to do with it.

Traveler information encompasses several time frames. It includes static route and schedule information, which may change several times per year. It includes daily and hourly information on major service disruptions. Finally, it includes information on the expected time of arrival for the next vehicle, information that may change on a minute-by-minute basis. Table 3.5 (static information) and Table 3.6 (real-time information) show the types of traveler information provided.

TABLE 3.5 Static Traveler Information (based on published schedule)

System	Description	Impacts
Pre-Trip Transit Information Systems	Provide information at origin prior to start of the trip.	- Convenience - Total travel time (find a better route)
In-Terminal / Wayside Transit Information Systems	Provide information at station, stop, or other location along route. Passenger Information Displays, Monitors, VMS, sign boards to display arrival and/or departure times of buses/trains	- Convenience - Total travel time (find a better route)
In-Vehicle Transit Information Systems	ADA compliant next-stop announcement/ display systems, destination signs	- Convenience
Multi-modal Traveler Information Systems	Provide information on transit along with other modes. Passenger Information Displays, Monitors, VMS, sign boards to display arrival and/or departure times of buses/trains	- Convenience - Total travel time (find a better route)

TABLE 3.6 Real-Time Traveler Information

System	Description	Impacts
Pre-Trip Transit Information Systems	Similar to Static but based upon current network status and alerts	- Convenience - Total travel time (find a better route) - Service Reliability (avoid disruptions)
In-Terminal/Wayside Transit Information Systems	Passenger Information Displays, Monitors, VMS, sign boards to display arrival and/or departure times of buses/trains	- Convenience - Total travel time (find a better route) - Service Reliability (avoid disruptions)
In-Vehicle Transit Information Systems	Information on connecting services.	- Convenience - Total travel time (find a better route) - Service Reliability (avoid disruptions)
Multi-modal Traveler Information Systems	Passenger Information Displays, Monitors, VMS, sign boards to display arrival and/or departure times of buses/trains	- Convenience - Total travel time (find a better route) - Service Reliability (avoid disruptions)
Personal Information Systems	Via e-mail, PDA, pagers, etc	- Convenience - Total travel time (find a better route) - Service Reliability (avoid disruptions)

Basic route and schedule information has been available for years. In recent years, however, new channels have been added to enable passengers to access this information, including automated phone systems, the Internet, and hand-held devices. Another recent innovation is the deployment of automated itinerary planners. With an automated itinerary planner, the passenger gives an origin, destination, the date of travel, and a desired departure or arrival time. The system then returns a suggested route or routes, along with estimated departure and arrival times.

Information on major service disruptions has traditionally been available through the media (local television and radio stations), and in-station and in-vehicle announcements. ITS technology has assisted the distribution of information on major service disruptions in two ways:

- With improved communications and automatic vehicle location the transit operator may have more timely knowledge of a disruption.
- New communications channels enable more riders to be informed of the disruption:
  - Transit operator web site
  - E-mail / pager systems
  - Multimodal information center with both Internet and phone access
  - Message board or public address announcements at transit stops and on vehicles.

Until recently, specific information on next-vehicle arrival has not been available. However, the use of AVL and improved communications enables the transit operator to know when a vehicle is expected to arrive at a particular location and thus to inform passengers.

Improved traveler information provides two major benefits to transit passengers:

- It provides reassurance (e.g., “I will only have to wait x more minutes, not hours.”)
- It enables the passenger to make a better transit path decision (e.g., to find a new route when a disruption occurs on the usual route).

Traveler information must have four characteristics in order to be useful:

- Relevant to the traveler’s need at that time (for example, a commuter facing a service disruption on his usual route usually does not need information on scheduled departures for that route)
- Accurate
- Supplied at a point in the journey where passengers can use it
- Easily obtained, at a low cost.

In the Transit ITS Impact Matrix, traveler information is split into five areas:

- Pre-trip Transit Information Systems
- In-terminal/Wayside Transit Information Systems
- In-vehicle Transit Information Systems
- Multi-modal Traveler Information Systems

- Personal Information Systems.

Pre-trip Transit Information Systems

This is defined in the Transit ITS Impacts Matrix as, “Transit information that is obtained before departing on a trip. Can be static and/or real time, and may include transit routes, maps, schedules, fares, park-and-ride lot locations, transit trip itineraries, etc. Media supporting pre-trip information include the telephone, Internet, electronic kiosks, fax machines, television, etc.”

Pre-trip information generally includes basic route and schedule information, even though information on major service disruptions and next-vehicle arrival time is sometimes available. Transit trip itineraries may be most helpful in the larger, more complex transit systems, where several possible routes exist for an origin-destination pair.

The use of automated pre-trip information is widespread, with over 300 deployments in the United States (Casey, 2002).

One survey done in London, United Kingdom indicates that improved pre-trip information may have some impact on demand. According to the Transit ITS Impacts Matrix, “A survey of users of London Transport's ROUTES computerized route planning system revealed that 80% of callers made the trip about which they inquired, 30.4% changed their route based on info received, and 10.4% made a trip they would not otherwise have made via transit.”

In-terminal / Wayside Transit Information Systems

In many transit systems, basic route and schedule information has been available in-terminal for years, via solutions such as a posted timetable. Two recent innovations include

- Improved capability to inform passengers of major service disruptions, via better communications within the transit operator
- Real-time information on next-vehicle arrival.

The use of automated wayside information is moderately widespread, with 167 deployments in the United States (Casey, 2002).

Although real-time information is popular among passengers, there is little quantitative information on the impact on demand for transit. In Helsinki, Finland a real-time transit vehicle arrival display system was implemented on one tram line and one bus route. A customer survey indicated 16% of tram passengers and 25% of bus passengers reported that they increased their use of the line/route because of the displays.

In London, the London Transport Countdown System provides real-time bus arrival information. The Transit ITS Impacts Matrix reported the following results for a survey of bus riders:

- 82% said information displayed was acceptably accurate,
- 64% believed service reliability improved,
- 83% said time passed more quickly knowing that the bus was coming, and
- 68% said their general attitude toward bus travel improved.

In-vehicle Transit Information Systems

According to the Transit ITS Impacts Matrix, an in-vehicle system "Automatically provides visual and/or audio announcements on transit vehicles. Typically, announcements include next stop, major cross road, transfer point, landmark, and destination information. Additional information, such as public service announcements and advertisements, may be provided at other times."

Such systems are in widespread use due to Americans with Disabilities Act (ADA) requirements. Another use of an in-vehicle system, although not as widespread, is to inform passengers of the status of connecting services.

Impacts on demand have not been quantified.

Multi-modal Traveler Information Systems

Multi-modal systems provide both transit and highway information, via various channels, such as Internet, telephone, and kiosks. For example, several traffic information web sites provide links to transit information.

Surveys of commuters indicate that such information may have some impact on demand. For example, in Seattle, WA, a survey conducted of SmarTraveler users indicated that, based on improved information, 5% to 10% change modes. A survey in San Francisco showed similar results (Transit ITS Impacts Matrix, accessed in 2003).

Personal Information Systems

Personal Information Systems are “Traveler information that is subscriber based or tailored to meet an individual's needs (e.g., travel profile). May include incident notification, transit vehicle arrival alert, or other information. Information is received via e-mail, personal digital assistants, pagers, etc.” (Transit ITS Impacts Matrix)

Impacts have not been quantified.

3.2.5 Transit Safety / Security

Safety and security systems include cameras (both in-vehicle and in-station), silent alarms, covert microphones and intercoms, and achieve three primary benefits:

- Improved transit employee safety
- Improved transit passenger safety
- Reduction in vandalism and false claims.

TABLE 3.7 Safety and Security Impacts

System	Description	Impacts
On-vehicle surveillance	Includes surveillance cameras, hazardous material sensors, on-board microphones and covert alarms	- Improved vehicle operator and traveler security - Reduced vandalism and false claims
Station surveillance	Includes surveillance cameras, hazardous material sensors, on-board microphones, covert alarms, and intrusion detection	- Improved vehicle operator and traveler security - Reduced vandalism
Incident response	Includes response scenarios, first responder coordination, mobile command and control	- Improved safety - Improved service reliability

In Denver, it was reported "assaults on bus operators and passengers dropped by 20% after the Denver Regional Transit District (RTD) implemented its AVL/CAD system, which contained a silent alarm and covert microphone feature." (ITS Impacts Matrix)

The systems see widespread use. Of the 351 smaller transit systems surveyed in the United States (Casey, 2002), 66 have operational or planned surveillance cameras, 52 have operational or planned silent alarms, while 17 have operational or planned covert microphones.

Unless passengers are currently avoiding the transit system because it is perceived to be unsafe, the impacts of safety and security systems on demand are likely to be minor.

3.2.6 Transportation Demand Management

Table 3.8 presents ITS options for demand management.

TABLE 3.8 Transportation Demand Management Impacts

System	Description	Impacts
Dynamic Ridesharing	Non-recurrent rideshare matching	- Total travel time - Convenience - Cost
Automated Service Coordination (Mobility Management)	Mobility management and "one stop shopping" for transportation in an area. Combined Sched. AVL, fare, etc.	- Convenience - Total travel time (find a better route)
Stations Cars and Access Support	Use of technology to extend areas accessible to transit	- Convenience - Access time (station cars improve access to transit)
Pedestrian ITS (control and management)	Pedestrian flow monitoring and guidance to assist pedestrians within transit centers and stations or in their travel to/from the station	- Convenience - Access time
Parking Management & Guidance	Parking lot capacity monitoring, guidance, and guidance both within and between lot locations.	- Convenience - Access time
Mulitmodal Transportation Management Centers	Facility that combines traffic, transit, communications, and / or control.	- Reliability

Dynamic ridesharing is rideshare matching for individual trips. Informal systems (usually at the entrance to a HOV facility) exist in several locations. More formal systems, with computerized matching, have not seen much success.

Dynamic routing and scheduling involves route diversion to meet requests for service. It may range from a full-fledged paratransit operation to minor route deviations from fixed route transit. It is a new concept, with unknown impacts.

Automated service coordination is a cooperative arrangement among multiple transportation operators to provide coordinated services. Issues with automated service coordination are more institutional than technical, and few quantitative impacts have been documented.

Transportation Management Centers are facilities that combine traffic and transit data collection, communications and control. Quantitative impacts have not been documented.

Summary

Technology areas that have seen wide deployment and may have a significant impact on demand include Fleet Management (including transit signal priority), Traveler Information and Electronic Fare Collection.

Aspects of fleet management with a significant impact on transit demand include AVL and transit priority treatment. AVL sees widespread use, and there is considerable interest in transit priority treatment. The available evidence suggests that the effective use of AVL can significantly improve service reliability. Use of transit priority at traffic signals reduces in-vehicle travel time and may enhance service reliability. Improvements to service reliability can reduce out-of-vehicle time.

Traveler information has generated intense interest and is popular among travelers. With the use of new communications channels over the past five years (Internet, hand-held devices), it is a rapidly evolving area. It has not, as yet, reached its full potential in terms of either the information provided to passengers or in the channels used to reach those passengers. Although some potential benefits have been identified, their impact is not well established. Benefits include

- Improved ability for new passengers to effectively use a transit service
- Reduced and more pleasant wait times for vehicles
- Improved ability for passengers to avoid service disruptions by choosing different paths.

The impact of Electronic Fare Collection is highly location-specific, because it depends on both the legacy system and on whether fare policies are being changed. However, EFC systems are being widely deployed.

Safety and security systems are likely to have little impact on demand, except in those situations where the transit service is perceived as dangerous.

Some of the Transportation Demand Management initiatives, such as dynamic ridesharing and dynamic routing/scheduling may have an impact on demand, but the use of these initiatives is not widespread.

CHAPTER 4

Advanced Fleet Management

Advanced Fleet Management comprises automatic vehicle location (AVL) and other systems that make use of AVL data. In the literature and in the remainder of this section, such systems are often referred to as automatic vehicle location, even though they include other components such as silent alarms, automatic passenger counters, engine condition monitoring, and computer-aided dispatch.

Simply knowing the vehicle's latitude and longitude provides little value. Much greater value is provided when AVL data are combined with other information such as street location, bus schedule, passenger boardings and alightings, driver messages, and the like.

Information from an AVL system can be used in three ways:

- Used on-board the vehicle in real-time (e.g., stop announcements and displays for the bus operator)
- Stored for later download (e.g., maintenance data and passenger counter data)

- Sent to transit agency headquarters in near real-time (e.g., vehicle location)

Figure 4.1 shows an AVL configuration that is used only for on-board announcements.

FIGURE 4.1 **AVL Used for On-board Announcements**

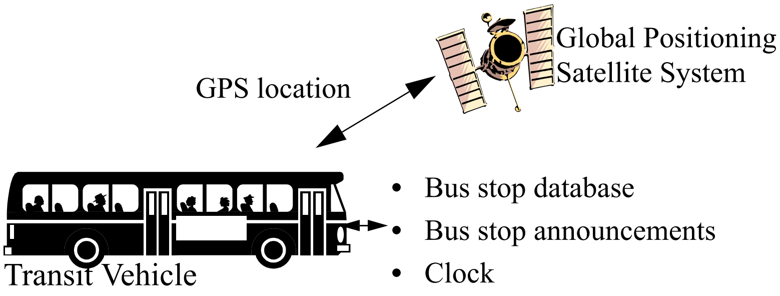


Figure 4.2 depicts a system where the vehicle location, passenger count, and maintenance information is stored and periodically downloaded for use in service planning.

FIGURE 4.2 **AVL Used for Service Planning**

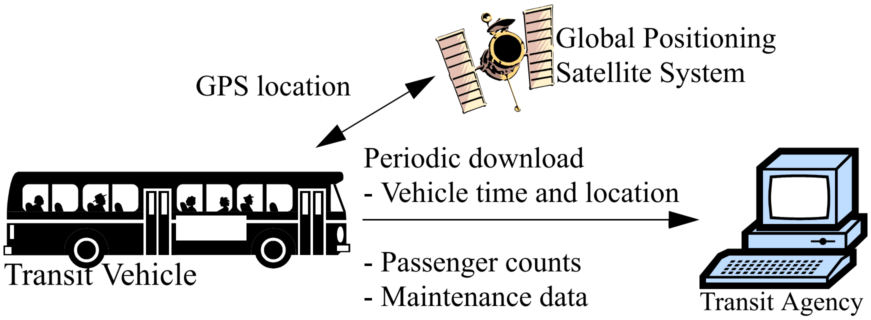
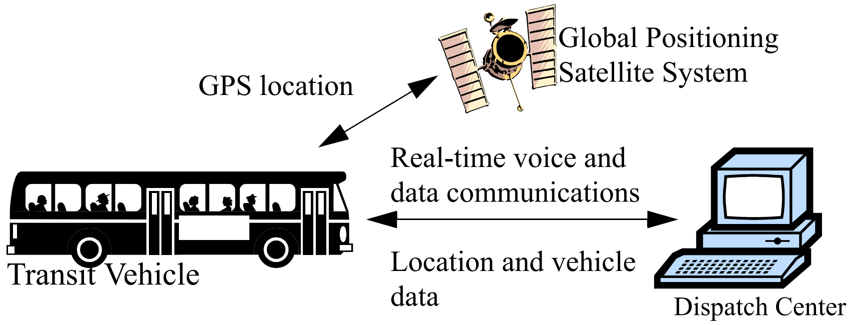


Figure 4.3 depicts a configuration where vehicle information is sent to the dispatch center in real-time. It is this last configuration that enables real-time intervention.

FIGURE 4.3 **AVL Used for Real-time Control**



Vehicle location technologies include wayside/corridor detection and global positioning systems (GPS). Most new AVL systems use GPS. Wayside detection locates vehicles along a pre-defined corridor. GPS locates the vehicle no matter where it is, although GPS may need to be supplemented in urban canyons, deep valleys, and other locations where an insufficient number of GPS satellites are visible.

Communications for operations includes voice and data communications. Data communications often involves the use of in-vehicle mobile data terminals (MDT) or personal mobile data entry. Mobile data terminals can be used to give real-time schedule feedback and messages to the bus operator. They also enable the operator to send pre-defined messages.

One or more systems can be installed on the transit vehicle:

- Mobile data terminals (mentioned earlier)
- Vehicle component monitoring
- Automated stop announcements
- Automatic passenger counters
- Silent alarms and covert microphones

The mobile data terminals enable bus operators to exchange pre-defined digital messages with the dispatch center, thus saving bandwidth. Vehicle component monitoring may reduce maintenance costs and enhance fleet reliability. Automated stop announcements help the transit agency to meet Americans with Disabilities Act (ADA) requirements. Automatic passenger counters record boardings and alightings at each stop, thus facilitating better service planning. Silent alarms and covert microphones improve safety and security by enabling the bus operator to call for help when an incident occurs. The dispatch center can then monitor events on the bus via the covert microphone.

Systems at the dispatch center include tools to assist in the use of the data, both for real-time operations control and for service planning. Fixed route computer aided dispatch (CAD) systems (for real-time use) may include one or more features:

- Disruption identification and service restoration. The system can identify early, late, off-route, or bunching problems and provide recommendations for restoring service.
- Connection protection. The system can recommend service responses to potential missed connections.
- Flex-route. The system can provide route deviation based on passenger request.
- Incident response. The system can enable a coordinated response to incidents.

Systems that support service planning include geographic information systems, data archival, and advanced scheduling and runcutting software.

AVL and related systems may be used to improve service reliability (and thus out of vehicle travel time), in vehicle travel time and comfort. Table 4.1 shows some common uses of AVL and related systems.

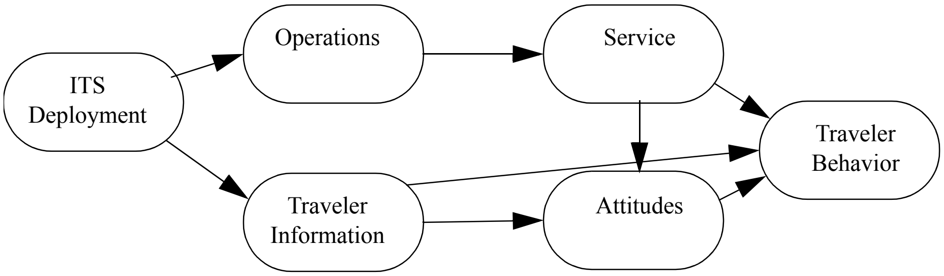
TABLE 4.1 AVL and Related Systems

Functionality	How used	Benefit area(s)
Display correct time of day to bus operator and passengers	Encourage on-time operation by bus operator	Reliability
Automated stop announcements	Aids passengers who are unfamiliar with the route Aids all passengers during poor weather conditions or at night Aids visually impaired passengers	Comfort
Schedule feedback to bus operator	Encourages on-time operation	Reliability
Digital messages to/from bus operator	Reduce radio bandwidth Manage connections	Reliability
Real-time control from central dispatch	Manage off-schedule buses, with system-wide visibility	Reliability Comfort
Archive arrival/departure information	Improve service planning and scheduling	Reliability In-vehicle time (tighten overly slack schedules) Out-of-vehicle time
Archive passenger counts	Improve service planning and scheduling	Comfort
Maintenance information	Better target vehicle maintenance	Reliability

4.1 Impact Linkages

Figure 4.4 is the impact linkage diagram that was discussed in Chapter 3.

FIGURE 4.4 Generic Impact Linkages



AVL information may be used in one of several ways. It may be used ***on-board*** the vehicle (either by the bus operator or for on-board announcements). It may be ***saved*** and used by the transit agency for planning. Finally, it may be sent to the transit agency dispatch center in ***real-time***. Figures 4.5 through 4.7 show impact linkage diagrams corresponding to these three uses.

FIGURE 4.5 AVL On-board Usage

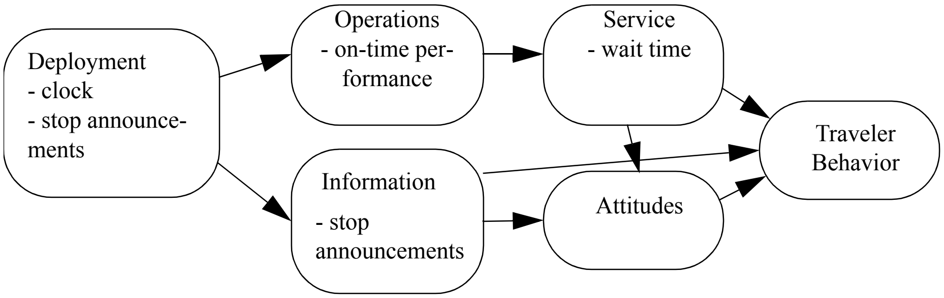


Figure 4.5 depicts the impact of a system that is only used to provide accurate on-board clock and stop announcements. The clock may facilitate on-time performance, while the announcements provide information to passengers. If on-time performance is improved, this may reduce passenger wait time.

FIGURE 4.6 **AVL Planning Usage**

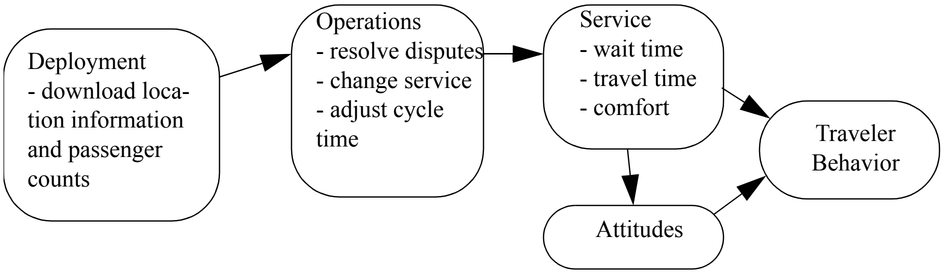


Figure 4.6 depicts the impacts of a system used for service planning. Since no information is provided directly to travelers, the "Information" block has been removed. AVL information can be used to resolve disputes (e.g., was the bus running early or not?), to make adjustments in service (e.g. putting more buses on an overcrowded route), and to make adjustments in cycle time, either to improve service reliability or reduce excess running times.

FIGURE 4.7 **AVL Real-time Usage**

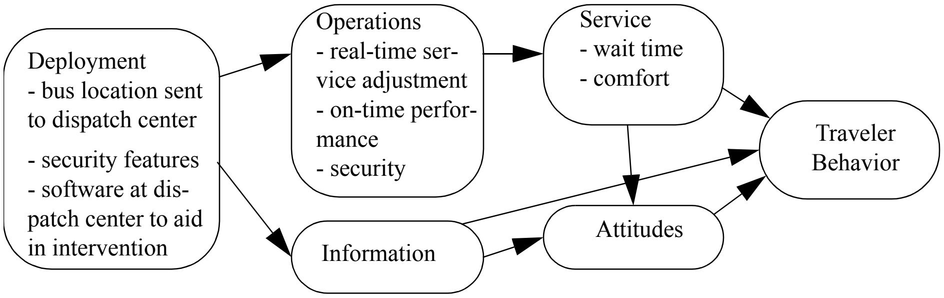


Figure 4.7 shows some of the impacts of a system that is used for real-time intervention. If the dispatch center knows the location and status of all vehicles, headways can be managed and effective solutions to service disruptions can be implemented. This may reduce overcrowding on some vehicles, thus increasing passenger comfort. The improved regularity of service will reduce passenger wait time.

Real-time AVL information may also be used to feed displays of when the next vehicle is due to arrive. This aspect of passenger information is covered in Chapter 6.

The next three sections explore several of the links depicted in the above figures. Section 4.2 examines the link from deployment to operational improvements. Section 4.3 examines the link from operational improvements to improvements as seen by the passenger. For example, it discusses the impact of poor service reliability on passenger wait time. Section 4.4 examines the link from service improvements to changes in both attitudes and behavior.

4.2 AVL Service Impacts

AVL information may be combined with other technologies, such as computer aided dispatch (CAD). These combined technologies may lead to improved transit service in several ways.

First, the combination of AVL information and a data archival function may be used to improve service planning, so that resources may be redeployed to places where they will be used more effectively. This may reduce overcrowding on some routes.

Second, the AVL system may influence on-time performance via several mechanisms. When AVL is combined with an on-board display such as a mobile data terminal (MDT), the accurate on-board clock and schedule feedback may change bus operator behavior. With CAD, the real-time location information at the transit agency dispatch center may enable real-time recovery strategies. Finally, the information may be used to identify situations where scheduled run times are too short, so that they may be adjusted.

AVL/CAD systems have several capabilities that enhance real-time control of the system:

- Bus operators are provided with the correct time of day, so that trips may originate on time
- Bus operators receive real-time feedback about on-time performance

- Dispatchers receive alerts if a bus is running late or early
- Central dispatch knows the status of the system at a glance (In the absence of decision support systems, this is more helpful for small systems.)
- Dispatchers can send messages to a group of buses
- Buses can send pre-defined messages about problems. These include breakdowns, the bus being full, and the bus being delayed.
- Buses can send messages regarding transfers. The ability for targeted bus-to-bus messages on transfers is particularly valuable. Before messages were available, requests to hold for a transfer would come in all at once to the dispatch center (as one would expect in a pulse system), and the dispatcher would sometimes be overwhelmed.
- AVL can tie into signal preemption systems, so that a late bus may request priority at traffic signals in order to catch up with its schedule.

Based on AVL/CAD data, several corrective actions can be taken:

- Short turns: A strategy where a vehicle turns around short of its final destination in order to fill a large gap in service on the return trip.
- Run express: a strategy according to which a vehicle skips consecutive stops. Passengers are warned at the station before the station where expressing begins and they get off the vehicle if their destination is a stop at the expressing part of the route. It can be implemented either by expressing a bus down a different street, such as a parallel roadway, or expressing vehicles to a later point in the trip.
- Deadheading: a vehicle skips a number of stops starting at a terminal
- Only dropping passengers off
- Holding vehicles at stops
- Inserting extra vehicles
- Overtaking. A bus is permitted to pass another bus.
- Signal prioritization to return buses to schedule

The 1995 FTA report, “Adaptive Control of Transit Operations,” lists examples of past research on the use of control strategies to improve the reliability of transit service. Models have been developed (primarily in the rail sector) that address deadheading, expressing, and holding strategies.

Third, AVL information, when coupled with security systems, can enhance safety and security on-board the vehicle.

Fourth, AVL information, when coupled with real-time passenger information, can be used to inform passengers of next-vehicle arrival, delays, and service disruptions on a real-time basis.

4.2.1 Empirical Evidence: AVL/CAD Impact on Transit Supply

Two major documented impacts of AVL/CAD on transit supply are improved on-time performance as well as scheduling and service optimization.

On-time Performance

A number of agencies have reported improvements in schedule adherence after the implementation of an AVL/CAD system.

TABLE 4.2 On-time Performance with AVL[1]

Who	Before	After	Comment
Kansas City, MO/KS	80%	90%	"On-time" is defined as one minute early to three minutes late. Improvement was the result of a 21% reduction in late buses and a 12% reduction in early buses.
Portland, OR	69%	83%	"On-time" is defined as one minute early to five minutes late.
Baltimore, MD		up 23%	Test involving two bus routes
Milwaukee, WI	90%	94%	28% decrease in the number of buses running more than 1 minute behind schedule
Denver, CO	88%	89.6%	
Hamilton, ON	82%	89%	

The Portland, Baltimore, Milwaukee, and Denver systems all included computer aided dispatch, mobile data terminals and silent alarms (Hill, 1993, and AVL Successful Transit Applications, 2000). The Baltimore system, implemented in 1990, used LORAN-C (LOng RAnge Navigation) for vehicle location while the others used global positioning satellites (GPS), sometimes supplemented by dead reckoning. Implementation details were not reported for Kansas City and Hamilton.

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[1] From Transit ITS Impacts Matrix and APTS Benefits Report.

In Portland, Oregon, Tri-Met reported an improvement in on-time performance from 69% to 78% in 1997 after implementing AVL/CAD (Strathman et al., 2000). From 1997 to 2001, Tri-Met improved its overall on-time performance further, from 78% to 83%, by using AVL data to adjust schedules. Bus bunching (headways below 70% of their scheduled value) declined by 15% for eight routes representative of Tri-Met's service typology after the agency implemented its AVL/CAD system. Furthermore, average run times decreased by 3% (1.45 minutes) on these same eight routes. The report states that,

> Comparing the before and after data revealed several benefits of the AVL and CAD systems. These benefits include a 9.4% improvement in on-time performance measured at the final destination of the routes under study; improvements at earlier points on the route were likely higher. The variability in the headways between buses decreased by 5% after the implementation of the improvements. No significant change was measured in the average run times for buses along the routes, with run times remaining about 1% longer than their scheduled values. The average coefficient of variability for bus run times did improve by 18% however, and no route experienced an increase in run time variability. The benefits indicated by the comparison of before and after data are consistent with the improved control available to transit supervisors after the implementation of the AVL and CAD systems.

Denver Regional Transit District (RTD) improved on-time performance from 88.0% to 89.6% after implementing its AVL/CAD system. The percentage of routes late decreased from 7.12% to 4.5%; however, the percentage of routes early increased slightly from 5.19% to 5.3%. The report (Weatherford, 2000) states that,

> Since AVL was implemented, the transit system has improved quality service. Between 1992 and 1997, RTD decreased the number of vehicles that arrived at stops early by 12%, decreased the number of passengers per vehicle that arrived at stops late by 21%, and decreased the number of customer complaints by 26% (per 100,000 boardings). In part, these improvements were the result of improved schedule adherence.

A number of agencies reported benefits other than improved on-time performance. For the Denver RTD hours of service loss due to maintenance road calls decreased 13.2% between 1995 and 1996. Between 1993 and 1996, miles per maintenance road call increased 33% and the maintenance repeat rate decreased 39%. Denver RTD attributes the improvements to its CAD/AVL system (Transit

ITS Impacts Matrix). In a study of timed transfers, Hall (1997) found a modest savings (20 seconds /passenger) from using AVL.

Table 4.3 lists information from the ITS Deployment Analysis System (IDAS) database (version 2.3) identifying on-time performance improvement from the use of AVL:

TABLE 4.3 **IDAS Database: On-Time Performance Improvement from AVL**

Result	**Source(s)**
Baltimore - On-time performance increased by 23%	from Assessment of ITS Benefits: Early Results - Mitre) also from ITS Benefits: Continuing Successes and Operational Test Results by Mitretek
Denver - 23% decrease in lost service hours in part due to improved radio reliability	from ITS Benefits Database, February 2001 - Mitretek Systems. Originally form U.S. DOT, Volpe Transportation Center, August 2000
Denver - Increase between 12% and 21% in schedule adherence on various routes	from What Have We Learned about Intelligent Transportation Systems? December 2000 U.S. DOT/ FHWA
Kansas City - 12.5% increase (from 80% to 90%) in schedule adherence	from What Have We Learned about Intelligent Transportation Systems? December 2000 U.S. DOT/ FHWA
Kansas City - Cut number of buses needs for its routes by 9%	originally from ITS Technologies in Public Transit: Deployment and Benefits, 1995 - Jones
Kansas City - On-time performance increased by 12%	from Assessment of ITS Benefits: Early Results - Mitre also from ITS Benefits: Continuing Successes and Operational Test Results by Mitretek
Milwaukee - On-time performance increased by 28%	from Assessment of ITS Benefits: Early Results - Mitre also from ITS Benefits: Continuing Successes and Operational Test Results by Mitretek
Milwaukee- Increase of 4.4% (from 90 to 94%) in schedule adherence	from What Have we Learned about Intelligent Transportation Systems? December 2000 U.S.DOT/ FHWA
Other transit systems have reported reductions in fleet size of 2% to 5% due to efficiencies of bus utilization	ITS Benefits: Expected and Experienced, 1996 – MITRE Corporation
Other transit systems have reported reductions in fleet size of 4% to 9%	from Intelligent Transportation Systems: Real World Benefits, 1998 - Apogee/Hagler Bailly originally from ITS Technologies in Public Transit: Deployment and Benefits, 1995 - Jones
Portland - 9.4% improvement in on-time performance measured at final destination	from ITS Benefits Database, February 2001 - Mitretek Systems; originally from Transportation Quarterly Vol. 54 No.3 (Summer 2000): 85-100

Both Tables 4.2 and 4.3 show a wide variety of results. This occurs for four reasons. First, there may be some variability in what was implemented and how it was used. For example, an AVL system that only makes automated stop announcements and shows the bus operator the time of day would be expected to result in little if any on-time performance improvement. However, if the AVL system is combined with CAD to enable real-time control strategies, or the archived data is used to improve schedules, the expected performance improvement should be larger. Second, there may be considerable variation in the prior performance of the transit system. If a transit system is performing well prior to the implementation of AVL/CAD, there is only limited room for improvement. If the transit system has maintained on-time performance by building excess slack into vehicle schedules, the benefit of AVL may take the form of improved vehicle utilization and reduced in-vehicle time (as schedules are tightened) rather than an improvement in on-time performance. Third, there may be variability in the accuracy of the measurement of on-time performance, particularly in the absence of an AVL system. Finally, the definition of "on-time" varies from agency to agency. This will also lead to some variability in the results.

Scheduling and Service Optimization

In some cases, scheduled running times are longer than necessary. This wastes resources and contributes to high in-vehicle travel time because the vehicle often has to wait at scheduled time points. A rule of thumb is that layover time should be at least 10% of the cycle time. Often, the layover times are 20% or more. Although some of the excess layover time may be necessary due to a desire for clockface headways[2], some represents a misestimation of the required cycle time. Using information from AVL to adjust schedules may enable a reduction of 2 to 5% in fleet size *(*Transit ITS Impacts Matrix, accessed in 2003)*,* and a cost reduction of 4-9%[3]. Specific examples include a reduction in travel time on some

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[2] For example, suppose a route uses three vehicles and has a round trip time (not including recovery) of 50 minutes. The minimum cycle time would be 55 minutes, which would imply a headway of approximately 18 minutes. However, it may be better to use a headway of 20 minutes (cycle time of 60 minutes) so that the schedule repeats each hour and is easier to remember.

[3] AVL also reduces data collection costs, particularly when it is coupled with automatic passenger counters. Although this does not have a direct impact on transit supply, it may enable improved service planning at lower cost.

routes by 10% based on AVL data (Kansas City). As a result, KCATA was able to cut 7 buses out of 200 (APTS Benefits, 1995).

4.3 Impacts of Improved Operations on Passenger Service

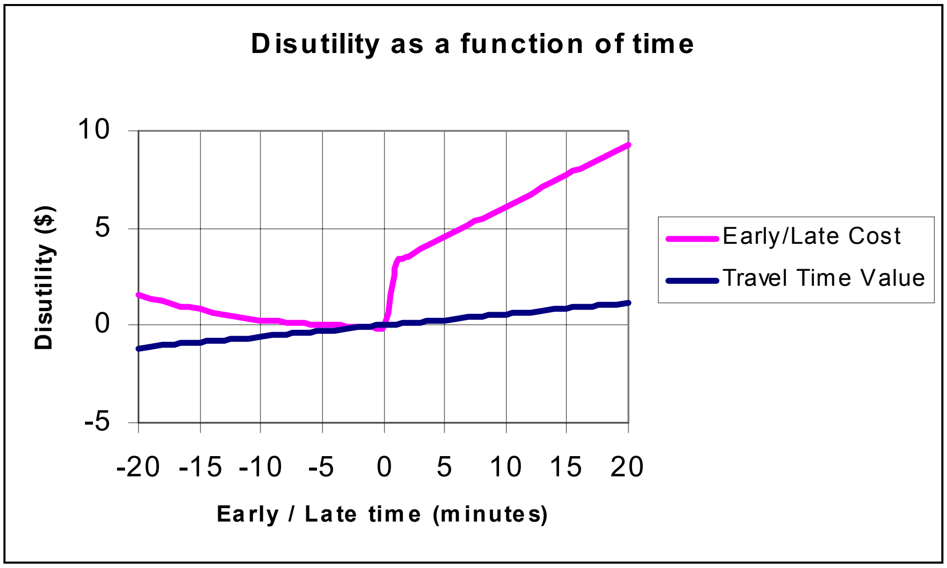
To understand the impact of improved operations (on-time performance, more regular headways) on passengers, it is important to first understand what is valued by passengers. Then the impact of the improved operations can be assessed.

4.3.1 Value of On-time Performance

Passengers value on-time performance. Several studies from the 1960s and 1970s, cited in (Abkowitz et al., 1978) indicate that passengers view “arriving at the intended time” as one of the most important attributes, more important than a fast trip. Reliability was also found to be an important determinant of passenger departure time behavior, with passengers responding to unreliable service via earlier departures.

Poor reliability has several impacts on passengers. One is that it leads to longer wait times for a vehicle, possibly in uncomfortable conditions. It may make for a less comfortable in-vehicle experience, because the poor reliability may result in some vehicles being overcrowded. Finally, it makes it less likely that passengers will be able to arrive at their destinations at an intended time. In NCHRP 431, Small and others (1999) present results from a stated preference survey of several thousand motorists along a corridor in California. Similar to the previous results, they found a small penalty for being early, but a much larger penalty for being late. Their best model without socioeconomic characteristics (Model 15) presented early/late costs for work trips (Figure 4.8). Note that the early/late cost is larger in magnitude than the travel time cost. When non work trips are considered, the penalty for being late (the "bump" from 0 to 1 in the graph) drops from $2.87 to $1.80. When socioeconomic characteristics were considered, it was found that families with children place a higher penalty on being late, while low income households placed less of a penalty on arriving early. Another finding from this report was that one minute of standard deviation of wait time had about the same value to travelers as two or three minutes of in-vehicle travel time.

FIGURE 4.8 **Disutility as a Function of Early/Late Time**



4.3.2 On-Time Performance and Passenger Disutility

An improvement in on-time performance will have several impacts on passengers, none of which are adequately modeled now:

1. Average waiting time will be reduced. For high frequency services, where passengers are assumed to arrive randomly, this reduction follows the formula

$$E(W) = \frac{1}{2}\left(E(H) + \frac{Var(H)}{E(H)}\right) \qquad \text{(Osuna and Newell, 1972).}$$

   The reduction in wait time is proportional to the change in the variance of the headway. With perfectly reliable service, the variance of the headway is 0, and the expected wait time is simply 1/2 of the headway.
2. For low frequency services, where passengers time their arrivals in accordance with a published schedule, the reduction in wait time will be larger.
3. Comfort will be increased, because a more reliable service will have more even passenger loads, and thus fewer overcrowded vehicles. With more even passenger loads, the variance of in-vehicle travel time may also be reduced.

4. The variability of waiting time is reduced, and passengers are less likely to be subject to an excessive delay.
5. For services with headways in the 10 to 15 minute range, improved service reliability may make it profitable for travelers to time their arrivals in accordance with the schedule, rather than arriving randomly. This will enable a further reduction in average wait time.

Possible impacts of improved reliability will be explained in three steps. First, we will review what might happen to demand model parameters should a reliability term be included. Second, we will develop in-vehicle travel time equivalents for random passenger arrivals on a 10-minute headway route with varying degrees of on-time performance. Finally, we will examine timed passenger arrivals on a 10-minute headway route.

Inclusion of a Reliability Term in Mode Choice Models

One could imagine a formulation where the "cost" of waiting is a function of both the average wait time and its standard deviation. For simplicity, we will express "cost" of waiting in minutes of in-vehicle travel time (IVTT). A minute of standard deviation is assumed to be worth 2 minutes of IVTT (following NCHRP 431), while a minute of average wait time is assumed to be worth K_1 minutes of IVTT.[4] K_1 is a constant that will be determined later.

First, consider the perfectly reliable service where vehicles are evenly spaced and passengers arrive randomly. Therefore, the wait time has a uniform distribution between 0 and the headway (H), where H is in minutes. The expected wait time is H/2 and the standard deviation is $H / \sqrt{12}$. Note that like the expected wait time, the standard deviation of wait time is also proportional to the headway. The total "cost" of waiting includes an average wait time component ($K_1(H/2)$) and a standard deviation component ($2H / \sqrt{12}$). Combined, this is $(K_1 + 1.15)(H/2)$ minutes of IVTT.

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[4] It would be wise to re-examine the assumption that a minute of standard deviation is worth 2 minutes of IVTT, since NCHRP 431 is based on auto users. Although it appears that both auto drivers and transit users care about travel time reliability, the extent to which results from NCHRP 431 can be transferred to a transit environment is not known.

Second, consider a less than perfectly reliable service where passengers arrive randomly. Empirical evidence and limited simulation modeling suggests that the standard deviation of wait time will still be roughly proportional to the headway, but its magnitude will be somewhat larger. The total utility of waiting (normalized to in-vehicle time) might be $(K_1 + 1.4)(H/2)$ minutes of IVTT.

Finally, consider the model where the standard deviation of wait time is not explicitly considered. Here, the total utility of waiting (normalized to in-vehicle time) is $K_2(H/2)$. The value of the constant K_2 is usually between 2 and 2.5.

In order for the formulations with and without explicit consideration of reliability to produce the same results, K_1 should be close to 1.

Wait times for transit generally involve high variability, a variability that often increases as average wait times increase. The high wait time coefficient of 2.5 typically used may largely be a result of this high variability, a variability that is often strongly correlated with average wait time.[5] It would be worthwhile to test this hypothesis, by seeing what happens to the coefficient of expected wait time when measures of the variability of wait time are explicitly included in models. Meanwhile, since the formulations that follow do explicitly include measures of service reliability, the value of the expected wait time will be assumed to equal the value of in-vehicle time.

Route with Random Passenger Arrivals

Consider a route where successive vehicle arrivals are independently gamma distributed. The route has an average 10-minute headway. The expected wait time and standard deviation of wait time is given in Table 4.4. A cost of waiting is also computed, under the assumption that 2 minutes of standard deviation has the same value as 1 minute of average wait time, which in turn has the same value as 1 minute of IVTT. Therefore, the total cost of waiting is

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[5] In travel demand modeling wait time is generally considered to be more onerous to travelers than in-vehicle time, with a higher disutility per minute of wait time. It it not clear, however, whether this higher disutility is due to the physical discomforts of waiting, or whether it is due more to passenger anxiety as to when the vehicle will arrive. It should be noted that in some situations (e.g. a bus stop shelter with adequate seating in a benign climate) waiting does **not** involve substantial physical discomfort.

(EQ 1)

$$CostOfWaiting = ExpectedWaitTime + 2StdDevWaitTime$$

Note that for 88% on-time performance, the total cost of waiting is almost exactly equal to 2.5 (H/2), consistent with the coefficient for wait time currently seen in mode choice models.

TABLE 4.4 **Route with 10-Minute Headway and Random Passenger Arrivals**

On-time% (vehicle arrival)	**73%**	**81%**	**88%**	**95%**	**100%**
E(wait time) (minutes)	5.9	5.6	5.4	5.3	5
StdDev(wait time) (minutes)	4	3.75	3.5	3.3	2.9
CostOfWaiting (minutes)	13.9	13.13	12.4	11.9	10.8

Since advanced fleet management may result in a 10-15% improvement in on-time performance (i.e., moving one or two columns to the right in Table 4.4), the on-time performance benefit of advanced fleet management may be equivalent to 0.5 to 1.5 minutes in-vehicle time. This is under the assumption that the expected wait time is worth the same as in-vehicle time. If we assume that the expected wait time is worth more than in-vehicle time, then the on-time performance benefit becomes higher when expressed in terms of in-vehicle time.

Route with Timed Passenger Arrivals

If we assume that passengers are aware of the schedule and can time their arrivals in accordance with that schedule, the benefit of improved on-time performance becomes greater. The cost of waiting was recomputed based on the assumption that passengers can arrive at the ideal arrival time in accordance with the schedule (typically, just a few minutes before the vehicle is expected to arrive):

TABLE 4.5 **Route with 10-Minute Headway and Timed Passenger Arrivals**

On-time% (vehicle arrival)	**73%**	**81%**	**88%**	**95%**	**100%**
E(wait time) (minutes)	4.2	3.6	3	2.7	0
StdDev(wait time) (minutes)	3.2	2.9	2.5	2.3	0
CostOfWaiting (minutes)	10.7	9.4	8.0	7.4	0

Since it is impossible for a passenger to time his or her arrival at the bus stop perfectly, the actual cost of waiting will be several minutes higher than indicated in Table 4.5. Observations of bus and rail passengers in London during the peak period (Joliffe and Hutchinson, 1975) indicates that approximately 50% of the passengers will attempt to time their arrivals when the advantage in doing so reaches 5 minutes. With a 10-minute headway, it is not likely that a passenger will find it worthwhile to time his or her arrival at the bus stop. However, with longer headways, there is an advantage in timed arrivals. Consider, for example, a 15-minute headway. With random passenger arrivals, the expected wait time is at least 7.5 minutes, and the total cost of waiting will range from 15 to 20 minutes (depending on the on-time performance). With timed passenger arrivals, the expected wait times and cost are much lower (Table 4.6)

TABLE 4.6 **Route with 15-Minute Headway and Timed Passenger Arrivals**

On-time% (vehicle arrival)	**73%**	**81%**	**88%**	**95%**	**100%**
E(wait time) (minutes)	4.4	3.8	3.2	2.9	0
StdDev(wait time) (minutes)	3.5	3.1	2.7	2.6	0
CostOfWaiting (minutes)	11.3	10.0	8.6	8.2	0

The on-time performance impact of advanced fleet management may be to move one or two cells to the right in Table 4.6. This represents an improvement of between 1 and 3 minutes, a greater improvement than is realized under the assumption of random passenger arrivals.

Discussion

It should be emphasized that the results in Tables 4.4, 4.5 and 4.6 depend on a two key assumptions, assumptions that should be re-evaluated:

- Following the discussion above (***Inclusion of a Reliability Term in Mode Choice Models***), minute of expected wait time has the same "value" of a minute of in-vehicle time.
- A minute of standard deviation of wait time has the same value as two minutes of in-vehicle time.

4.3.3 Impact of Reliability on Wait Time and Passenger Arrival Behavior

As noted earlier, poor reliability has a significant effect on wait times. A number of New York City bus routes were observed to have wait times 5 – 72% in excess of what wait time would be with perfectly reliable service, with a typical value of about 50% (Traveler Response to Transportation System Changes, 2000) One study, cited in this same document, indicated if 10% of buses are cut randomly on a high frequency service, average passenger waiting time will increase by 20%. The effect is even worse for low frequency service, where a cut run means passengers will have to wait an extra (long) headway.

Under the assumption of random passenger arrivals, a perfectly regular service (Var(H) =0) will yield an expected wait time of 1/2 of the headway. As Var(H) increases, the expected wait time increases. However, as service becomes more regular, passengers may find it more advantageous to time their arrivals in accordance with the vehicle schedule. Therefore, the wait time benefit from increased reliability may be greater than that computed under the assumption of random passenger arrivals. A number of years ago, passenger behavior was observed in suburban London (Abkowitz et al., 1978). A finding was that on routes that were reliable (low standard deviation of headway), passengers were able to time their arrivals in accordance with the vehicle schedule. Therefore, the observed wait time was far less than what one would expect with random passenger arrivals. However, on the routes with poor reliability, passengers realized less advantage by timing their arrivals; thus, wait times were closer to what one would expect with random passenger arrivals. Consider the following pair of observations, both at bus stops with an observed bus headway of approximately 24 minutes.

TABLE 4.7 **Observed Wait Times as a Function of Service Reliability**

	Headway (minutes)			**Wait Time (minutes)**	
	Scheduled	**Observed**	**Std. Dev.**	**Random Arrival**	**Observed**
More reliable	23	23.9	2.2	12.9	5.8
Less reliable	20.3	23.5	10.7	14.0	13.1

Theoretical Model

Consider the following model of a bus service, where a vehicle has a given headway, scheduled arrival time, and a standard deviation for that arrival time. Two questions are to be answered:

- What is the ***passenger*** arrival time that minimizes expected wait time?
- What is that wait time, and how does it compare to wait time for random passenger arrivals?

Two cases are considered, based loosely on the routes in Table 4.7. Case 1 is the more reliable service with a 23-minute headway, an arrival time standard deviation of 2.2, and a scheduled arrival time of 23 (times are in minutes). Figure 4.9 shows the distribution of bus arrival time for Case 1. It is modeled using a gamma distribution with an offset from zero. If "on-time" is defined as between 1 minute early and 5 minutes late, the vehicle in Case 1 is on-time 87% of the time. Case 2 is a less reliable service, with a 23-minute headway, a scheduled arrival time of 23 but a standard deviation of 10.7. Figure 4.10 shows its distribution of bus arrival times.

FIGURE 4.9 Distribution of Bus Arrival Time (Case 1)

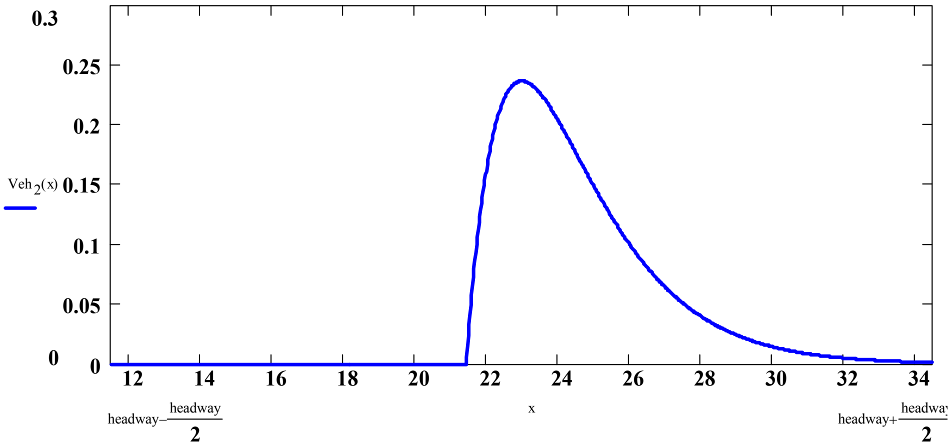
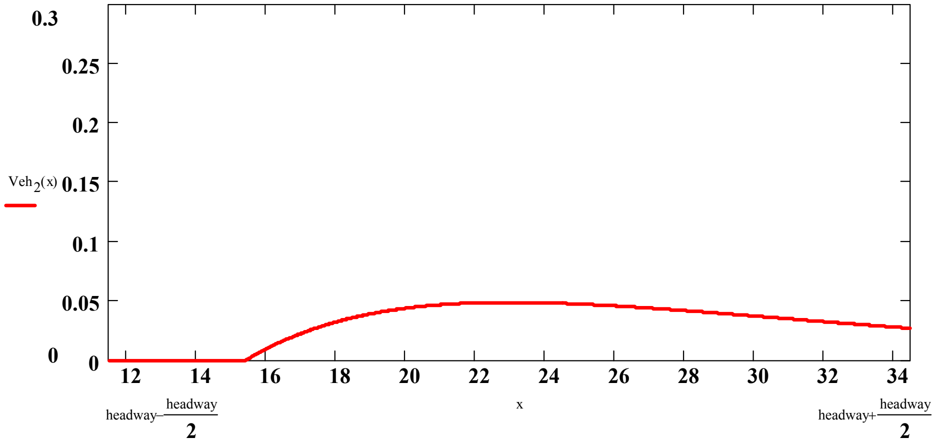


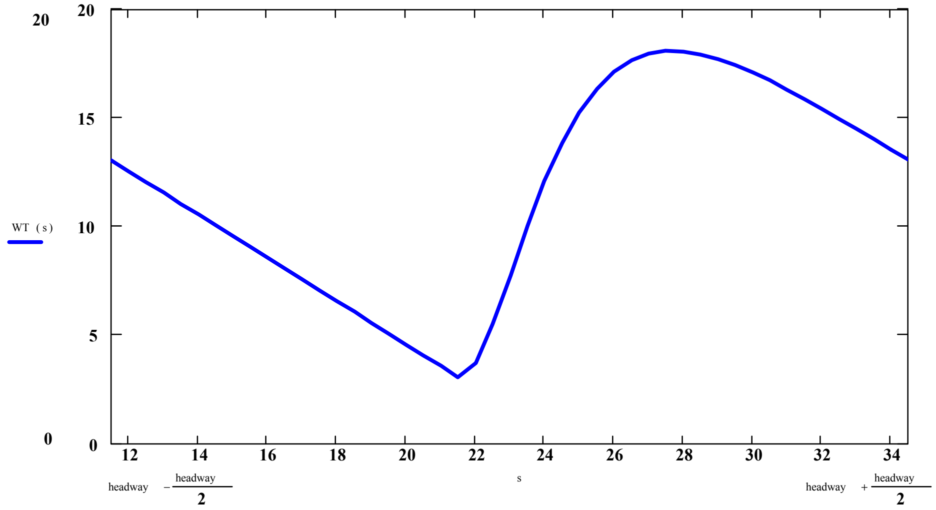
FIGURE 4.10 **Distribution of Bus Arrival Time (Case 2)**



In Case 2, the transit vehicle will arrive between 1 minute early (22) and 5 minutes late (28) only 28% of the time.

Returning to the more reliable service (Case 1), Figure 4.11 shows the expected waiting time as a function of passenger arrival time.

FIGURE 4.11 **Wait Time as a Function of Passenger Arrival Time (Case 1)**



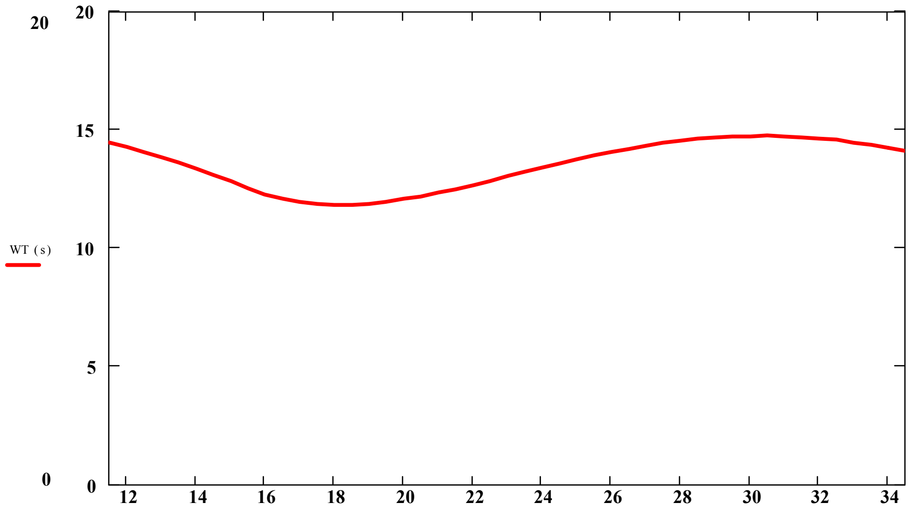
Here, with the vehicle due to arrive at time 23, the ideal passenger arrival time is at between time 21 and 22, yielding an expected wait time of approximately 3 minutes. Actual wait times will probably be longer for two reasons:

- Passengers can't time their arrivals exactly. Even with perfectly well-informed passengers and perfectly reliable service, passengers may arrive a few minutes earlier than the optimal time.
- Some passengers may not be aware of the schedule.

For this reliable route, Figure 4.11 shows a significant difference between minimum and maximum wait times, indicating that it is worthwhile for passengers to time their arrivals in accordance with the vehicle schedule.

Expected passenger wait times for the less reliable service (case 2) are much larger (Figure 4.12), and passengers gain less of an advantage by timing their arrivals at the bus stop.

FIGURE 4.12 **Wait Time as a Function of Passenger Arrival Time (Case 2)**



In wait time modeling, it is commonly assumed that passengers will arrive randomly for service with a headway of 15 minutes or less. This analysis suggests that the assumption that wait time equals 1/2 the headway may be an over-simplification. In cases were service is reliable, passengers can reduce their wait times to less than 5 minutes by timing their arrivals with the vehicle schedule (recall Figure 4.11). This suggests that for reliable services with headways in the 10 to 15 minute range, passengers may find it beneficial to time their arrivals in accordance with the schedule.

Implications for Transit Agency Measures of Service Reliability

Transit agencies traditionally measure on-time performance at the end of the route, usually regarding "on-time" as being between 1 minute early and 5 minutes late. This measure fails to address two important facts:

- Passengers care about on-time performance at their boarding and alighting points, not at the endpoint for the route.
- Passengers on high frequency routes care more about evenly spaced headways than adherence to a particular schedule. Consider as an example two routes each with a headway of six minutes. On the first route, buses arrive at the passenger's boarding point either 1 minute early or 5 minutes late (Thus a pair of buses arrives every 12 minutes.) On the second route, all the buses are 6 minutes late. From the transit agency perspective, the first route is 100% "on time," although it is providing poor service to passengers. The second route is 100% late from the transit agency perspective, although it is providing good service to passengers, with evenly spaced 6-minute headways.

To deal with this issue, some transit agencies have adopted a headway-based service standard for high frequency routes (MBTA, 1996).

4.3.4 Summary

The relationship between improved operations and the passenger perception of service is complex. This section explored three aspects of that relationship. First, in the exploration of passenger attitudes towards being early and late, it was found that there may be a high penalty attached to being "late" (Figure 4.8). Therefore, a reliable service with mediocre but consistent average travel time may be preferred to a service that has highly variable travel times. We hypothesized that the disutility of waiting is a function of both the average and standard deviation of the wait time. Second, we used this hypothesis to assess the passenger disutility under various probability density functions of bus arrival times, ranging from those with low variance to high variance. We found that a 10% improvement in on-time performance may be worth more than 1 minute of in-vehicle travel time. Finally, we examined the relationship between service reliability and passenger arrival behavior at a bus stop, and found that more reliable service makes it more beneficial to passengers to time their arrivals in accordance with the schedule, rather than arriving randomly. Therefore, the wait time improvement with improved service reliability may be greater than what is commonly assumed under a model that assumes random passenger arrivals.

4.4 Ridership Impacts of Advanced Fleet Management

Service reliability is not explicitly included in most models of mode choice. Because it is not explicitly included, but is important, it is likely that other variables in the mode choice model are acting as proxies:

- Alternative specific constant (ASC). The alternative that is perceived as unreliable might have a high ASC.
- Wait time coefficient. For transit services, the wait time is typically highly variable (anywhere from 0 to the headway, or even more). The high wait time coefficient may reflect the passenger's dislike of this variability.
- Transfer penalty. A transfer presents opportunities for missed connections. The transfer itself may not be onerous to passengers, but the possibility of a missed connection is.

4.4.1 Empirical Evidence: AVL Impact on Transit Demand

Since AVL is usually combined with other changes, isolating the impact of AVL is difficult. In Denver, ridership on RTD buses increased between 1992 and 1994. This coincided with both the introduction of the AVL system and with a service expansion. Therefore, as stated in the evaluation report (Weatherford, 2000), "There is no evidence of increased ridership…in the RTD transit network as a result of the AVL system."

The Toronto Transit Commission estimates that service improvements from its AVL system will conservatively result in a 0.5% to 1.0% increase in ridership. The IDAS database indicates a 1 to 2% increase in ridership, as cited from the

Mitretek Interim Report, Incorporating ITS into Corridor Planning: Seattle Case Study, June 1997.

Total revenue ridership increased 4.8% between 1993 and 1997 for the Milwaukee County Transit System. The agency attributes the improvement to its CAD/AVL system. In Portland, OR, from fall 1999 to fall 2000, weekday ridership increased by 450 for one route after Tri-Met used AVL data to adjust the route's headways and run times.

The literature has suggested that advanced fleet management may result in a 1% to 2% ridership increase. Is this reasonable? Consider a transit trip with a 5 minute expected wait time where on-time performance is improved by between 5 and 10 percentage points. This would be the equivalent of a 1 - 2 minute reduction in in-vehicle time (Table 4.4 and Table 4.5). The incremental logit formulation is used to evaluate this change.

$$P_i' = \frac{P_i \cdot e^{\Delta U_i}}{\sum P_k \cdot e^{\Delta U_k}}$$

where

- P_i = The existing probability of using mode *i*
- P_i' = The new probability of using mode *i* based on the potential improvement(s)
- $\Delta U = U_i' - U_i$
- U_i' = The new utility for mode *i* based on the potential improvement(s)
- U_i = The existing utility for mode *i*
- k = The set of all available modes

For these two cases, the new mode share is calculated as follows:

TABLE 4.8 Change in Mode Share

		On-time performance improvement	
	Original	**Low (~5%)**	**High (~10%)**
IVTT Coefficient	-0.025	-0.025	-0.025
Equivalent Improvement in IVTT	5	1 minute	2 minutes
Δu_t	N/A	0.025	0.050
Original Mode Share	20%		
$P_{t\_orig} \exp(\Delta u_t)$		0.205	0.210
$\Sigma P \exp(\Delta u)$		1.005	1.010
New Mode Share		20.4%	20.8%
% Change in Mode Share		2%	4%

The analysis indicates that a small increase in ridership is plausible.

4.5 Conclusions and Recommendations

A major impact of advanced fleet management is improved reliability of transit service. More reliable service results in lower wait times, lower likelihood of arriving "late" (hence, less need to hedge by leaving early), and possibly less crowding (evenly spaced buses will tend to have more even passenger loads, thus making it less likely that one bus will be overcrowded and the next bus empty). Although reliable service is recognized as important, service reliability is not explicitly incorporated in planning models.

A second impact of advanced fleet management is improved service deployment, because the transit agency can better identify errors in scheduling, and overcrowded or under-utilized routes.

4.5.1 What We Can Do Now

The IDAS model suggests that the impact of advanced fleet management can be captured via a percentage reduction in both out-of-vehicle and in-vehicle time. Although a reduction in out-of-vehicle time is plausible, the magnitude of the impact is highly dependent on the transit system in question. For example, one transit system may be well managed with highly reliable accurately scheduled service. From a service reliability standpoint, there may not be much benefit from advanced fleet management. On the other hand, another system may have unreliable service due to poorly deployed resources and poorly set schedules. Advanced fleet management may be of enormous benefit for that agency.

Given the range of possible impacts, it is impossible to suggest any specific changes to planning model parameters that should be made as a result of advanced fleet management.

In cases where accurate on-time performance information does exist, it may be possible to factor the information into planning models (See section 4.5.2).

Reasonableness Tests

Theoretical analysis indicates that an improvement in on-time performance by 5-10% might be worth approximately 1 or 2 minutes of in-vehicle time to the passenger. With the coefficient of in-vehicle time being typically –0.025, this translates into a change in utility of 0.025 or 0.05. For an origin-destination pair where the transit mode share is currently 20%, this corresponds to a 2 – 4% increase in ridership. The mode share would become 20.4% to 20.8%. This increase is based on two assumptions:

- Reliability is fairly poor to begin with. (If a transit system already offers reliable service, there is less room for improvement.)
- The transit agency does use the capabilities of advanced fleet management effectively, and realizes a significant improvement in service reliability.

To the extent that these assumptions do not hold true, the improvement in ridership will be less than calculated.

4.5.2 Improving Current Practice

To capture the impact of advanced fleet management, it is necessary to capture service reliability in our travel models. For the sake of consistency, reliability should be captured both for highway and transit trips. This effort involves three major tasks:

- Data collection

- Development of appropriate measures
- Model improvements

Data Collection

It requires more effort and more data to understand the distribution of travel times and headways than it does to estimate the mean travel time. For many transit routes, valid reliability information is not readily available. However, with the archival abilities of AVL, the capability now exists to measure service reliability at major boarding stops. With these measurements, data will exist to incorporate the impacts of reliability in mode choice models.

TCRP Web Document 23 (Furth et al., 2003) reviews some of the issues in using archived AVL-APC data. Earlier AVL systems would engage in polling at some interval of as much as several minutes. They would give location-at-time information, and the location reported may be nowhere near a timepoint. Location-at-time information is not nearly as useful as time-at-location information, where the location is typically a timepoint on the route. An effective workaround is to treat arrival at each timepoint as an event in the AVL system, so that time-at-location information is furnished for these timepoints. On the other hand, the design of APCs does consider the need to archive information. The authors note a number of differences in practices between the United States and Europe. Event recorders are popular in Europe. Although they were intended for incident management, it may be possible to download location and stop information at the end of each day. Also, in Europe, each stop tends to also be a timepoint.

Kimpel (2001) presents an effort to use AVL data from Portland, Oregon to assess transit service reliability and its impact on demand. In this work, schedule and headway delay variation were assessed at the route and timepoint level.

An accurate assessment of service reliability requires that three items of information be collected:

- Schedule adherence at each timepoint
- For high frequency routes, headway at each timepoint (this requires valid data for two successive buses)
- Running time for the route and for each timepoint along the route.

Development of Appropriate Measures

The mean travel time is a measure that is easily understood; measuring service reliability is more complex. Possible measures include (a) the standard deviation of travel time, (b) the variance of the travel time, (c) the likelihood of being "late" by some amount, or (d) some high percentile (such as the 95th) of the travel time. Also, while from a traveler perspective it may be best to measure reliability at the path level, it may only be possible to measure it at the link level. That is, for a transit passenger taking both a bus and a subway, is it possible to measure the reliability of the passengers intermodal trip, or do we somehow combine the separate bus and subway reliability measures?

Using the variance as a measure offers two advantages

- It captures the desire to give a greater weight to large excursions from the mean
- Under the assumption that link travel times are independent, the variance of the sum of these link travel times is equal to the sum of the variances on the individual links. This makes use of the variance computationally tractable.

However, use of the variance does not capture the skewness of typical travel time distributions. For example, one travel time might be uniformly distributed having no possibility of an extremely long travel time while another might be exponentially distributed having a substantial possibility of an extremely long travel time. Both distributions might have the same variance, but given the high cost to passengers for being "late," the exponentially distributed travel time would be viewed as much more onerous.

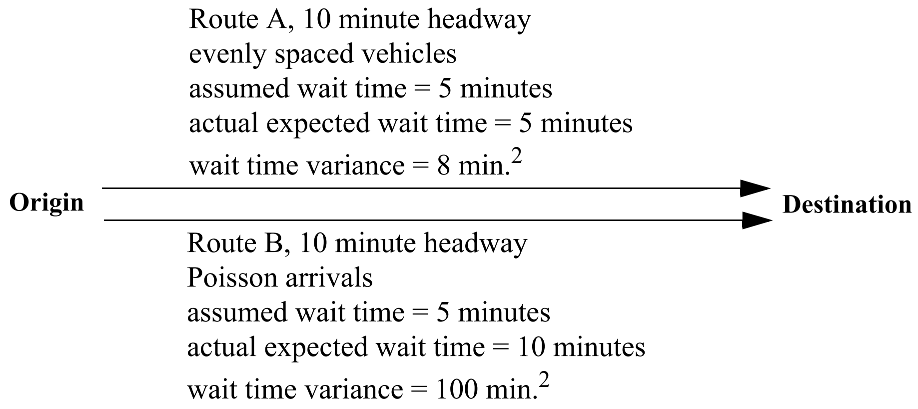
Model Improvements

Wait time is now generally assumed to be 1/2 the headway. We could imagine a generalized wait time that includes three concepts:

- Arrival pattern of passengers (random or in accordance with a schedule)
- Expected wait time
- Likelihood of a substantial delay.

With these changes, the wait time would more accurately reflect what is important to transit passengers. This generalized wait time concept could also be part of transit pathbuilding. Consider the example shown in Figure 4.13:

FIGURE 4.13 **Pathbuilding with Generalized Wait Time**



In standard modeling and path building, both routes would be viewed as equally desirable. In reality, passengers would view Route A as a much more desirable option.

Service reliability is extremely important to transit passengers. However, perhaps because it has been difficult to gather data on the actual on-time performance of transit services, reliability has, for the most part, not been explicitly included in planning models. This could change with the increasing popularity of AVL and related systems. First, one justification for these systems is their beneficial impact on reliability. This impact should be quantified. Second, these systems can provide a wealth of data on running times and schedule adherence, thus making it possible to gather the data that would be required to calibrate a model that includes service reliability.

CHAPTER 5

Transit Signal Priority

Transit signal priority (TSP) systems are designed to enhance transit operations by enabling bus or light rail vehicles to pass through signalized intersections more quickly.

Transit signal priority systems may be classified along several dimensions. One dimension is whether the priority scheme is applied at one intersection or network-wide. A second dimension is the selection of vehicles that are given priority. Progressively more complex levels of selectivity include the following:

- Use signal timings to favor all vehicles, including transit vehicles, on the corridor.
- Apply priority to all transit vehicles.
- Apply priority to selected transit vehicles (e.g., those that are running late or are crowded).
- Apply priority based on both transit vehicle characteristics (e.g., is the vehicle running late) and other network characteristics (e.g., is the cross street congested?). This is called Adaptive Priority.

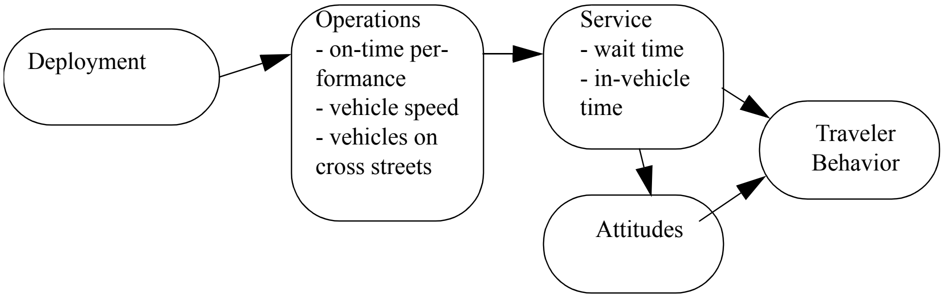
A third dimension is the scheme used to apply priority. A passive priority scheme might consist simply of optimizing signal progressions along the route, so they best match the movements of transit vehicles. Four types of active priority schemes can be applied to individual vehicles:

- Red truncation (early green). When a transit vehicle is waiting at an intersection, the red time is shortened to reduce its wait time.
- Green time extension. When a transit vehicle is approaching an intersection and the green signal is about to turn red, the green time is extended so the transit vehicle may clear the intersection.
- Change or insertion of a signal phase. A transit vehicle may receive its own green signal.
- Signal preemption. The current cycle of the signal is preempted to give priority to the transit vehicle. Signal preemption is typically used for emergency vehicles and not for transit vehicles.

5.1 Impacts on Transit Operations

Figure 5.1 shows the impact linkages of transit signal priority, from deployment to end user benefit. Since transit signal priority does not provide direct information to passengers, the Traveler Information block is not shown.

FIGURE 5.1 Transit Signal Priority Impact Linkages



Impacts fall into three major areas:

1. TSP may enable the transit vehicle to move faster, thus reducing in-vehicle travel time (IVTT)

2. TSP may enable more reliable transit service, thus reducing out-of-vehicle travel time (OVTT)
3. TSP may impact the performance of the intersection for other drivers. These include impacts on both the route of the transit vehicle and the intersecting street.

There is considerable literature on the impact of signal priority on transit operations. Accordingly, this section is divided into four sub-sections. The first is an elementary theoretical analysis of the expected effects of signal priority. The second section presents empirical results. The third section presents simulation results. The fourth section is a summary of several review papers and existing handbooks.

5.1.1 Elementary Theoretical Analysis

A signal priority scheme typically involves an extension of the green time for the street used by the bus at the expense of the green time of an intersecting street. The effectiveness of a signal priority scheme depends upon the characteristics of the intersection. At some intersections, the transit vehicle may be incurring minimal delay without signal priority, hence, a priority scheme will be of little benefit. In other cases, various constraints at the intersection may limit the amount of priority that may be offered. To illustrate these points, consider a priority scheme at one intersection, Main and Cross Streets. The bus runs on Main Street. The impacts of signal priority will depend upon a number of factors:

- Traffic volume on Cross Street, and the level-of-service[1] of the approach.
- Whether the length of the green for Cross Street is governed by traffic volume or by the needs of pedestrians crossing Main Street. For pedestrians, the minimum required green time is the duration of the Walk signal, plus a reasonable clearance interval based on the width of the street. The minimum duration of the Walk signal is typically 4 to 7 seconds, while the pedestrian clearance interval is given as W / 4 (ft. / sec.), where W is the distance from the curb to the middle of the farthest travel lane on the street. For example, on a street

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[1] Level-of-service is a concept used by traffic engineers to measure delay at an intersection or on an approach to an intersection. Level-of-service “grades” are given, from A to F. Level-of-service A means light traffic, while E and F indicate unacceptable levels of congestion

where the distance from the curb to the farthest travel lane is 60 feet, the pedestrian clearance interval would be 15 seconds, yielding a minimum green time of 19 to 22 seconds. Therefore, for wide streets, the time required for pedestrians to cross Main Street may act as a lower bound on the green time for Cross Street.

- Traffic volume on Main Street and the level-of-service of that approach
- Number of buses per hour requesting priority.

For the bus, Lin (2002) gives the expected delay reduction from signal priority at an isolated intersection without queueing as

(EQ 1)

$$\frac{1}{C}\left[R\delta + \frac{1}{2}(R^2 - R_{min}{}^2)\right]$$

where

R = bus red time without signal priority

R_{min} = minimum red time (governed by pedestrians crossing)

C = cycle time

δ = maximum green extension for the bus

This equation has two terms related to benefits. The first term, involving Rδ, is the benefit from green extension. The second term, involving R^2-R^2_{min}, is the benefit from red truncation.

Furth (2004) presents a formula for both expected intersection delay and delay reduction from green extension. His formula is based on a deterministic queuing model. The expected signal delay (without priority) is given as

(EQ 2)

$$\left(\frac{R^2}{2C}\right)\left(\frac{1}{1 - v/s}\right)$$

while the delay reduction from the green extension is

$$\left(\frac{\delta}{C}\right)\left(R + \frac{\delta}{2}(1 - v/s)\right) \qquad \text{(EQ 3)}$$

where v/s is the arrival rate divided by the discharge rate at the intersection. The other variables have the same definition as those in Lin’s equation. Using cycle times and green extension times similar to those in (below), the savings calculated by this formula are about 3 – 15% lower than those derived from Lin’s formula.

Table 5.1 presents some expected per-intersection delay reductions based on these equations.

TABLE 5.1 **Expected Time Savings from Green Extension (85% saturation)**

R (sec.)	C (sec.)	δ (sec.)	a. Delay without TSP (sec.)	Delay Reduction (sec.)		% Delay Reduction	
				b. Furth	c. Lin	b/a (Furth)	c/a (Lin)
30	100	5	11	1.4	1.5	13%	14%
50	100	5	22	2.4	2.5	11%	11%
70	100	5	33	3.4	3.5	10%	11%
30	100	10	11	2.8	3	25%	27%
50	100	10	22	4.7	5	22%	23%
70	100	10	33	6.6	7	20%	21%
30	100	15	11	4	4.5	36%	41%
50	100	15	22	6.7	7.5	32%	34%
70	100	15	33	9.7	10.5	29%	32%

The computed savings increases when red truncation is added.   Table 5.2 shows the travel time savings given by both 10 seconds green extension and 10 seconds red truncation.

TABLE 5.2 Expected Time Savings from Green Extension and Red Truncation

R (sec.)	C (sec.)	δ (sec.)	a. Delay without TSP (sec.)	Delay Reduction (sec.)		% Delay Reduction (b + c) / a
				b. Red Trunc.	c. Green Ext.	
30	100	10	11	2.5	3	50%
50	100	10	22	4.5	5	44%
70	100	10	33	6.5	7	41%

Note that when both green extension and red truncation are considered, the calculated percent delay reduction appears to be somewhat larger than is typically observed in field situations. This is not surprising because the equations were developed for an ideal situation. It does, however, suggest that the formulas presented by Lin and Furth may be useful as an approximate upper bound on the benefit that may be obtained from TSP at an isolated intersection.

An extension of green time for the bus on Main Street must result in more red time on Cross Street. This increase in red time is effectively a temporary disruption to traffic flow on Cross Street. As traffic volume on Cross Street increases, it requires more time to recover from such a temporary disruption. The fundamental relationship from queuing theory that governs the wait time for traffic on Cross Street is that the wait time is proportional to

$$\frac{1}{1-(\lambda/\mu)} \tag{EQ 4}$$

where λ is the arrival rate of traffic on Cross Street, while μ is the service rate, which is the maximum rate that traffic on Cross Street may pass through the intersection. μ must always be greater than λ. The effect of bus signal priority on Main Street is to reduce μ for Cross Street. Where μ is much greater than λ, the impact is minor. However, the impact grows as μ approaches λ. Table 5.3 presents three possible situations:

TABLE 5.3 Impacts of Signal Priority

Cross Street Green Time/Traffic	Impacts
Cross Street traffic is light (λ is much smaller than μ). Green time is not constrained by pedestrians; therefore, green time is short.	Since the red time for Main Street traffic is already minimal, the impact of signal priority on bus delay will be small. The use of signal priority will have little harmful impact on Cross Street.
Cross Street traffic is light (λ is much smaller than μ), but, because Main Street is wide, green time for Cross Street is constrained by pedestrians crossing Main Street.	It will not be possible to shorten the green time on Cross Street; therefore, the benefit from implementing bus priority is limited. It may be possible to lengthen green time on Main Street, thus increasing overall cycle time. This, however, may create additional delays for pedestrians.
Cross Street traffic is heavy (λ approaches μ). Green time is governed by Cross Street traffic.	Signal priority may be disruptive to traffic on Cross Street. It may be possible to manage this by (a) using conditional priority, so that the disruptions occur less often or (b) increasing the green time on Cross Street (red time on Main Street) during a future cycle of the traffic signal.

In cases where Cross Street traffic is heavy, it may be possible to “give the green time back to Cross Street” by reducing green time on Main Street during a future cycle, thus helping to reduce the traffic queue on Cross Street. Such a strategy may be effective under the following conditions:

- Traffic is relatively light on Main Street,
- The green time on Main Street is not constrained by the needs of pedestrians crossing Cross Street,
- Bus service is infrequent, so that the reduced Main Street green time does not delay a future bus.

5.1.2 Empirical Results

Table 5.4 (from Baker et al., 2002) lists examples of TSP implementations:

TABLE 5.4 **Transit Signal Priority Implementations**

Location	TSP Strategy	Travel Time Savings	Comments
Portland OR, Tualatin Valley	early green, green extension	1.4 – 6.4%	bus, 10 intersections
Seattle WA, Rainer at Genesee	early green, green extension		50% reduction in signal related stops for prioritized buses 57% reduction in average traffic signal delay 35% reduction in bus travel time variability through the intersection side street effects were insignificant
Europe (5 sites)	various	6 – 42%	10/sec. intersection average reduction in transit signal delay 40-80% potential reduction in transit signal delay 0.3 – 2.5% increase in auto travel time
Seattle, WA, Rainier Ave, midday peak	early green, green extension	8%	bus, 3 intersections
Portland OR, Powell Blvd.	early green, green extension, queue jump	5 – 8%	bus, 4 intersections
Sapporo City, Japan	unknown	6.1%	9.9% ridership increase
Chicago, IL Cermak Road	early green, green extension	7 – 20%	Transit schedule reliability improved Decrease in vehicular delay (average 1.5 sec. with range 7.8 to –1.1) Increase in cross street delay (average 8.2 with range 4 – 37.9)
San Francisco, CA	early green, green extension		6 – 25% reduction in transit signal delay for LRT. Total travel time savings was not reported.
Minneapolis, MN Louisiana Ave	early green, green extension actuated transit phase	0 – 38%	bus, 3 intersections 23% (4.4 sec./veh.) increase in traffic delay Skipping signal phases caused some driver frustration
Los Angeles, CA Wilshire and Ventura Blvd.	early green, green extension actuated transit phase	8%	35% decrease in bus delay at signalized intersections

The ITS Deployment Analysis System (IDAS) benefits database suggests similar results for the reduction in bus travel time. Some are from actual implementations while others are from simulations:

- Portland - 5% - 8% reduction in bus travel time
- Oakland/Berkeley - Reduced delay for buses by 14% and average speed by 3.4% using passive priority strategies to favor transit, with small disbenefits to rest of traffic stream (1% increase in delay while number of stops decreased by 2%)
- Simulation - timing plans can reduce travel times to transit vehicles by 5 to 8% with bus volume of 50 or higher
- Oakland/Berkeley - Reduced delay by up to 6 seconds/intersection/bus on a major arterial with 21 signalized intersections
- Washington, D.C. - Travel times of transit vehicles reduced by about 6% when tested on 114 intersections with 300 instrumented buses, but total traffic performance worsened
- London - Average bus delay savings of 5 seconds/signal, about 22% improvement
- London - Bus delay savings of 10 seconds/signal in light traffic, about 70% improvement
- Turin - 20% increase in average bus speeds without disbenefits to rest of traffic
- Sydney - Reduction in travel time of 6% for LRTs with insignificant disbenefits to cross street traffic
- Portland - Total bus passenger delay decreased by 12.3%
- Seattle - 30% savings in delay for buses on transit priority lanes in mixed flow
- Seattle - 40% savings in delay for buses on transit priority lanes in HOV or bypass lanes
- Los Angeles - average travel time decreased by 25% on two routes
- Torino, Italy, UTOPIA - Private traffic average speed increased 9.5% to 15.9%, public transport speed improved 19.9%, in peak hours gains rose over 35%
- France and England - Reduction in transit travel times of 6% to 42%, with 0.3% to 2.5% increase in automobile travel time
- Sapporo, Japan - (5.7 km section) Bus travel times reduced by 6.1%

- Eindhoven, Netherlands - total delay during three busiest hours increased by 40 seconds per vehicle with absolute priority, bus delay fell from 27 to 3 seconds with absolute priority.
- Eindhoven, Netherlands - 90% of buses received zero-delay service under conditional priority.
- Valencia, Spain - 30% reduction in delay for vehicles already behind schedule

An implementation in Seattle was reported as reducing the standard deviation of the AM Peak travel time by 20%. Another implementation in Portland, OR reported a 9% improvement in on-time performance (Gross, 2003).

Selected Field Implementations

Helsinki

In Helsinki, Finland, a pilot project to implement real-time passenger information and signal priority was implemented on a tram line and a bus line, with field measurements being collected between 1998 and 2000 (Lehoten and Kumala, 2002). Signal delays were reduced by 44% and 48% on the tram and bus lines, respectively. Total travel times decreased 1% (21 seconds) on the tramline and 11% (about 3 minutes) on the bus line, primarily as a result of the reduced signal delay. However, stop times increased slightly, because drivers who were ahead of schedule made longer stops. On-time arrival improved by 22% on the tramline and 58% on the bus line.

London

In London, England, a number of strategies were implemented along a 22 km stretch of Uxbridge Road that is served by high frequency express routes (Hounsell, 1999). Between 1993 and 1996, bus priority lanes, pre-signals and bus gates were implemented. Later, three bus priority strategies were tested:

- bus priority
- selective bus priority with AVL
- bus priority using gating strategies.

Four priority strategies were used:

- Extensions only strategy - extended green time for buses detected towards the end of the normal green signal
- Extensions and recalls strategy (normal priority) - extended green time as well as green signal recall for buses arriving on red (subject to safety constraints)
- Extensions and recalls strategy (high priority) – extensions and recalls strategy with additional benefits for buses even at the expense of added delay for general traffic.
- Gating strategies. Signal timings are changed to move congestion away from the bus routes. This is done by reducing green times on the approach links to the critical link.

Table 5.5 presents the results on Uxbridge Road, for periods of moderate congestion, when spare green time was available.

TABLE 5.5 Uxbridge Road Results: Moderate Congestion

BUS SCOOT STRATEGY	Average Reduction in Bus Delay	Average Reduction in Bus Delay Variability
Extension Only	5%	4%
Extension and Recalls (Normal Priority)	20%	8%
Extension and Recalls (High Priority)	19%	11%

The gating strategies were also tested during periods of heavy congestion (AM Peak, Table 5.6).

TABLE 5.6 Uxbridge Road Results: Heavy Congestion

STRATEGY	Average Reduction in Bus Delay	Average Reduction in Bus Delay Variability
BUS SCOOT (Bus Priority Alone)	7%	10%
SCOOT (Bus Priority) & Gating	13%	12%

Eindhoven, Netherlands

In Eindhoven, Netherlands, three priority strategies were tested at one intersection (Furth and Miller, 2000):

- No priority for the bus
- Absolute priority (priority is applied to all buses)

- Conditional priority, with the bus only receiving priority when it was behind schedule.

Findings for this particular intersection showed that absolute priority resulted in a significant increase in cross-traffic delay. They also showed that conditional priority reduced the cross traffic delay to close to zero, while retaining most of the benefit for the buses. The authors also found that conditional priority reduced the variability of vehicle arrival times. On a day without priority, 15% of the vehicles were at least 3.3 minutes early, while 15% were at least 2.5 minutes late. With conditional priority, this band became narrower, with 15% of the vehicles at least 1 minute early, and 15% at least 2.2 minutes late.

Toronto

A number of adaptive signal control technologies, including transit signal priority, were implemented in Toronto (Greenough and Kelman, 1999). The implementation on a streetcar line resulted in a total delay reduction of 35%, with no significant impacts on side street queues. Results for buses are shown in Table 5.7:

TABLE 5.7 Toronto Results

Period	Reduction in round trip transit travel time	Reduction in round trip transit signal delay
AM Peak	34 seconds (2%)	61 seconds (30%)
Mid-day	84 seconds (6%)	74 seconds (40%)
PM Peak	69 seconds (4%)	79 seconds (37%)

One issue was noted that involved near-side stops. The system extended the green time while the vehicle was at the stop, but would typically reach the maximum phase length before the vehicle was ready to leave the stop. This increased the amount of time the vehicle had to wait for the following green phase. There were also reports of increased pedestrian delay due to the signal priority system.

Vancouver

In Vancouver, British Columbia (Cima et al., 2000), a conditional signal priority system (where vehicles receive priority when they are behind schedule) has resulted in reduced travel time variability. Reductions in variability of 29% in the AM peak and 59% in the PM peak were observed.

Portland, OR

In Portland, Oregon (Kimpel 2004), archived run time data were used to evaluate the impacts of signal priority on six route segments. The authors found that the impacts of signal priority were not consistent across routes, direction and time of day. Although run times tended to be somewhat faster, the results with respect to run time variability were inconclusive.

Los Angeles

Los Angeles carried out a detailed evaluation of their Transit Priority System in September 2000, a few months after the beginning of Metro Rapid service. A previous Los Angeles Department of Transportation (LADOT) study had indicated that for buses on Wilshire and Ventura Boulevards, approximately 20% of bus running time was spent waiting at signals. For the evaluation of the Transit Priority System, 13 Rapid buses were not given any priority over a 9-day period. The remaining 99 Rapid Buses had priority. Peak period run time data was analyzed for several segments of the two routes. The Transit Priority System reduced signal delays by 33 – 36% on the two routes. With signal delay accounting for about 20% of running time, this corresponds to a running time reduction of about 7% (1 to 6 minutes, depending on the length of the segment).

5.1.3 Simulation Models

Morgan and others (2002) used MITSIM to examine the impacts of signal priority on a route in Stockholm. With light traffic on the side street, there was little side street traffic impact with either the conditional (based on load or headway) or an unconditional priority scheme that applied to all transit vehicles. Both priority schemes led to a significant reduction in travel time and travel time variability. However, when side street demand increased, the unconditional priority scheme led to a great increase in side street travel time, while there was little increase in side street travel time with conditional priority.

Muller and Furth (2000) used a simulation model to examine the impacts of both bus priority and holding strategies[2]. Their simulated route consisted of four segments, each with an average running time of 10 minutes and a standard deviation of 2 minutes. Their primary measure was the central schedule deviation band, which is the range from the 15th percentile to the 85th percentile arrival time. Without control, the deviation band at the end of the third segment was –3.5 to 3.5 minutes, and the average wait time was 7 minutes (assuming that passengers arrive at the 2nd percentile time). With a holding strategy (do not allow buses to leave a timepoint early), the deviation band was reduced to 0 to 4.1 minutes, and the average wait was reduced to 1.9 minutes. With a combination of holding and conditional priority, the deviation band was reduced to 0 to 2.0 minutes, which suggests an average wait time of perhaps 1 minute.

Mirchandani et al. (2001) used the CORSIM model to examine priority strategies used in conjunction with the RHODES™ traffic adaptive signal control system. They examined travel time for all vehicles between two stops on the bus route, cross street delays, and average bus passenger travel times. With bus priority, they found a reduction of 4.6% - 6.39% in passenger travel time, depending on cross street volume. This was accompanied by a slight increase in cross street delay.

Chang et al. (2003) used INTEGRATION to examine the effects of conditional priority along a corridor in Virginia. They found an approximate 3 to 4% improvement in the standard deviation in trip time along the corridor.

Ngan et al. (2004) used VISSIM to evaluate transit signal priority along a corridor in Vancouver, British Columbia. They found TSP to be effective under certain conditions:

> A TSP application would be most effective under a traffic condition that has moderate-to-heavy bus approach volume, little or no turning volume hindering the bus movement, slight-to-moderate cross street v/c ratio, farside bus stop, and signal coordination for traffic running in the peak direction. More importantly, TSP could generate significant adverse impact on cross streets with high v/c ratios.

Rhaka and Zhang (2004) used INTEGRATION to evaluate a hypothetical isolated signalized intersection and found similar results to Ngan.

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2. A simple holding strategy may be to require that a bus that is running early to hold at a timepoint until its scheduled departure time.

5.1.4 Summary Papers

Table 5.8 (from Chada and Newland, 2002) shows a summary of efforts in several cities:

TABLE 5.8 Summary from Chada and Newland (2002)

Location	Travel Time Savings	Comments
Ann Arbor, MI	6%	TSP strategies included green extension, red truncation and skip phasing.
China	10%	No results reported for cross street
Los Angeles, CA	~8%	Also reduced number of stops. Estimate that of a total 25% time reduction, 30-40% of that was due to signal priority.
Seattle, WA	5 seconds/ intersection	Bus travel time variability down 35%

They gave a number of conditions favoring bus signal priority, including

- Express bus service
- Express bus service during off peak hours
- Farside bus stops
- Cross streets are NOT highly saturated (over 1 v/c ratio)
- No heavy volume intersections on the network
- No instances of two transit vehicles approaching one intersection
- AVL technology installed.

They note that as the saturation level of the intersection increases, the effectiveness of priority is reduced.

Soo and others (2004) summarized travel time impacts from a number of deployment and simulation results as shown in Table 5.9:

TABLE 5.9 **Transit Priority Strategy Impacts (from Soo et al., 2004)**

Strategy	**Deployment**	**Simulation**
Signal Optimization	2 – 5%	None
Green Extension (GE) Only	0 – 9.7%	0 – 6%
Red Truncation (RT) Only	None	1 – 10.6%
GE + RT	1.4 – 20%	1.6 – 14.2%
GE + RT + Queue Jump	0 – 18%	None
Combinations	1.8% - 28%	2.7 – 17.6%

They also noted that in both Portland, OR and Los Angeles, traffic signal delay was found to be roughly 20% of bus running time. This suggests that an upper bound of 20% on the run-time benefit.

Dale et al. (1999) presented a transit signal priority impact assessment methodology. They point out that there is considerable skepticism that must be overcome regarding the impacts of transit signal priority on traffic. To overcome this skepticism, there is a role for both simulation and field studies. Advantages of simulation include low cost, low risk, greater control, and greater ability to communicate the results via animation. Disadvantages of simulation include inability to perfectly replicate field traffic conditions and believability among stakeholders. They proposed several measures of effectiveness:

- Intersection Control Delay
- Minor Movement Delay
- Minor Movement Cycle Failures
- Bus Travel Times
- Bus Schedule Reliability (standard deviation of travel time)
- Intersection Bus Delay
- Average Person Delay
- Vehicle Emissions
- Accidents.

The Transit Capacity and Quality of Service Manual (TCRP Report 100, 2003) indicates a 3% to 15% travel time savings from bus signal priority. It also outlines several advantages and disadvantages:

Advantages

- Reduces control delay
- Improves reliability

Disadvantages

- Risks interrupting coordinated traffic signal operation
- Risks lowering intersection level-of-service, if intersection is close to capacity
- Requires on-going inter-jurisdiction coordination
- Buses on the cross-street may experience added delay greater than the time saved on the favored routes.

To conclude, there appear to be major findings from past implementations of transit signal priority:

- TSP can be effective at reducing transit travel times.
- Conditional TSP can reduce transit travel time variability, but this has not been as well quantified.
- TSP works best under the following conditions:
  - Far side stops
  - Non-saturated traffic volumes
  - Signal timings not greatly constrained by pedestrian needs.

Furthermore, characteristics of conditional signal priority, as compared to unconditional signal priority, include the following:

- Conditional signal priority requires more sophisticated logic, and information from the transit vehicle. With unconditional priority, the signal only needs to know that a transit vehicle is coming. With conditional priority, priority is only requested under certain conditions, conditions that are typically based on the on-time status (and possibly, the passenger loading) of the transit vehicle.
- Conditional priority has greater potential for reducing transit travel time variability.
- Conditional priority will have a smaller effect on cross street traffic.

5.2 Service Models

The previous section was concerned with documenting the impacts of transit signal priority. In this section, we discuss a few instances where TSP impacts have been incorporated into planning models.

In some areas (Dallas, Boston) transit signal priority is being represented as a reduction in link travel times for transit vehicles. In Boston, the reduction was derived via the use of a simulation model to assess the travel times on the proposed bus rapid transit route.

In IDAS, the default improvement in transit vehicle speed from signal priority is 6.3%. Given the results reported in the literature, this seems reasonable as a rough average.

As noted above several research efforts have used simulation (models such as VISSIM, CORSIM and MITSIM) to assess the impact of signal priority.

5.3 Conclusions and Recommendations

A well-documented impact of transit signal priority is reduced in-vehicle travel time. In some cases, there is also an impact on travel time variability, but this is not as well documented. Current practice is to represent transit signal priority as a reduction in transit link travel time. This reduction may be determined either via default values or by running a simulation model of the intersections in question. However, no explicit effort is being made to model the reliability impacts of signal priority, or to incorporate the reliability impacts in 4-step models.

The impact of a TSP strategy will vary greatly depending on several criteria by which it is implemented:

- The type of strategy that is implemented (signal optimization, green extension, red truncation, other options)
- The conditions under which priority is given (unconditional versus conditional priority)

- The aggressiveness of the strategy (e.g. what is the upper bound on the green extension provided)
- Frequency of bus stops, and whether they are near-side or far-side
- Current signal timings, and whether the signals are part of a progression
- Major street and cross street volume/capacity ratios
- Street width and pedestrian activity.

Therefore, great care is required in applying the observed or simulated benefits from one corridor in another corridor. At this point, correct evaluation of the benefits of TSP prior to implementation can be done through detailed simulation modeling and produce results that are important to the transportation planning process:

- Transit travel time savings
- Impact on roadway speed (including intersections) for other traffic (both on the street that the bus is operating on and the cross street)
- Improvements in transit service reliability.

5.3.1 What We Can Do Now

Current practice is to perform a detailed simulation on the corridor where transit signal priority is contemplated. Three measures may come out of such a simulation:

- Bus travel time
- Variability of bus travel time
- Impacts on other traffic.

Applying the new bus travel time is fairly straightforward. If there is a significant reduction in bus travel time variability, its impact could be modeled using techniques outlined in the chapter on Advanced Fleet Management.

A detailed simulation is expensive to implement. Therefore, when doing sketch planning, the following approach is suggested:

1. Evaluate each signalized intersection in the corridor. At the intersection level, readily available information includes the total cycle time C, the red time per

cycle faced by buses without priority R, the stop configuration (near side, far side, or no stop), whether the intersection is part of a progression, and the level-of-service on each intersection approach. The expected delay reduction from priority (green extension and red truncation) at an isolated intersection can be approximated using the formulas given in Section 5.1.1,"Elementary Theoretical Analysis" on page 91. These formulas were developed under idealized assumptions, as discussed earlier. The benefits given by them may be best viewed as an approximate upper bound on the actual benefit that might be attained.Table 5.10 presents expected delay reductions, from equation 1 in Section 5.1.1 In this table, cycle time is assumed to be 90 seconds. Note that the benefits of signal priority are largest when (a) the red time is large (i.e. the street that the bus is traveling on is not the major street at an intersection) and (b) when the priority strategy is aggressive, with a 15-second green extension or red truncation.

TABLE 5.10 **Signal Delay Reduction at an Intersection**

All times are in seconds			**Maximum Delay Reduction**		
Red Time	**Signal Delay without Priority**	**Maximum green extension and/or red truncation**	**Green Extension**	**Red Truncation**	**Both**
20	6.6	5	0.8	1	1.8
20	6.6	10	1.7	1.7	3.4
20	6.6	15	2.5	N/A[a]	N/A
30	11.5	5	1.7	1.5	3.2
30	11.5	10	3.3	2.8	6.1
30	11.5	15	5.0	3.8	8.2
45	19.6	5	2.5	2.4	4.9
45	19.6	10	5	4.4	9.4
45	19.6	15	7.5	6.3	13.8
60	27.9	5	3.3	3.2	5.5
60	27.9	10	6.7	6.1	12.8
60	27.9	15	10.0	8.8	18.8

---

a. A 20-second red time and a 15-second red truncation implies reducing the cross street green+clearance time to 5 seconds, which is generally not feasible.

2. Qualitatively evaluate whether the net benefit of signal priority is likely to be limited. In particular, four situations have been identified that will limit the benefit of signal priority:
   - Near side bus stops

- Poor (D – F) level of service on the cross street approach. In this case, providing signal priority on the main street might significantly increase congestion on the cross street approach.
- Much better level of service on the cross street approach than on the main street approach. This indicates that either (a) signal timings need to be optimized, or (b) something else is limiting the length of red time on the main street approach. This limit, for example, might include the time required for pedestrians to cross the main street.
- The intersection is part of a progression. In this case, it may be wise to first optimize the progression to best serve the needs of all users, including transit riders.

Reasonableness Tests

Reasonableness tests for transit signal priority should be applied at both the corridor and intersection levels. At the corridor level, the savings in bus travel time can be expected to be at most 15% (and most likely under 10%), but as noted earlier, this is highly dependent on characteristics of the priority system and of the corridor.

Example

In this example, the sketch planning technique outlined above is applied to a one-mile corridor with the following characteristics:

- Bus speeds currently average 10 mph, yielding a 6 minute running time
- All signals along the corridor have a cycle time of 90 seconds
- There are four signalized intersections, with red times of 20, 30, 45 and 60 seconds, respectively.
- V/C on the corridor is 0.85

Consider, first, a strategy that applies up to 10 seconds of green extension at each signalized intersection. The delay reductions may be taken from Table 5.10, and are shown in Table 5.11:

TABLE 5.11 Delay Reductions by Intersection

Intersection	Red Time	Delay Reduction (seconds)
1	20	2.2
2	30	3.3
3	45	5.0
4	60	6.7
Total		16.7

With a 6-minute running time on the corridor, the 17.2 seconds represents a running time improvement of approximately 4.8%.

If a strategy of 10-second red truncation is added to the 10-second green extension strategy, the total delay reduction increases to 30.6 seconds, which represents a running time improvement of approximately 8%.

Both of these results are consistent with the reasonableness tests, above, and with the results reported in Table 5.9 on page 104.

5.3.2 Improving Current Practice

Existing research has tended to report the results of specific real or simulated instances of signal priority. Because few efforts have been made to generalize these into rules that indicate where priority would be most effective and where it will or will not have a significant effect on cross street traffic, research in two areas should be undertaken:

- Development of rules for assessing the potential impact of signal priority, given priority strategy, bus service frequency, intersection geometry and current level-of-service on each approach to an intersection.
- Further assessment of the impacts of signal priority on reliability, and hence wait times for downstream passengers.

Finally, as systems are implemented, it is important that their impacts be carefully measured, including reports on delay reduction per signalized intersection. This measurement will aid in the ongoing refinement and improvement of the TSP after it is implemented.

CHAPTER 6 *Traveler Information*

Traveler information is a complex area that includes everything from Internet-based trip planners to stop announcements on-board the vehicle. Traveler information systems may be categorized along several dimensions:

1. When the traveler receives the information
   - Prior to the trip
   - At the boarding stop
   - Enroute

2. Must the traveler actively do something to receive (pull) the information, is it automatically sent (push) to the traveler, or is the information simply available with little or no effort on the traveler's part. Examples of information channels where information is pulled by the traveler include
   - Radio
   - Television
   - Internet
   - Phone
   - Kiosks

Examples where information is pushed to the traveler include

- In-station announcements
- On-board announcements.

There are also examples that don't fall neatly into either category:

- Pager and e-mail announcements. These are like "pull" systems in that an initial effort is required on the traveler's part for set up. However, once that effort has been made, they become "push" systems.
- Schedules and real-time information displays (reader boards) at transit stops. The information is not pushed to the traveler, but obtaining it requires little or no effort on the traveler's part.

3. What type of information is provided?

- Static information (routes, schedules). This is information that does not change on a day-to-day basis, and includes the route, schedule and stop locations.
- Real-time information. This information does change on a daily or more frequent basis. Within the area of real-time information, there appears to be a further breakdown into one of two categories:
  - . Information on major service disruptions (Because major disruptions are rare events, information about them can be updated manually, and is sent to travelers via the news media, the transit operator web site, in-station and on-vehicle announcements)
  - . Information on next-vehicle arrival (which, due to its high volume, is generally updated automatically)

Many transit agencies are attempting to provide information on major service disruptions. Fewer are providing next-vehicle arrival information, usually only on selected routes. For next vehicle arrival information, two approaches may be taken. One is to simply let the travelers know the locations of the vehicles so that they may draw their own conclusions about when the next vehicle will arrive. This approach, obviously, is of limited usefulness to travelers who are not familiar with the transit system.

The other approach is to provide an estimate of the number of minutes until the arrival of the next vehicle. In this case, predictions of vehicle arrival time are given starting (typically) 15 – 30 minutes before vehicle arrival.

Table 6.1 depicts the various information channels, categorized by static versus real-time and by where in the trip the information is accessed.

TABLE 6.1 Traveler Information Channels

	Static	Real-time
Pre-trip	- Printed maps and schedules - Static roadside signs - Transit agency information phone - Maps and schedules on the internet - Trip planner[a]	- Radio and TV announcements of disruptions - Dynamic message signs (e.g., parking availability at park & ride lots) - Transit system status on the Internet - Pager/e-mail notification
At transit stop	- Posted schedule at stop	- Reader board at stop
Enroute	- On-board stop announcements[b]	- On-board stop and service announcements (real-time information on connecting services)

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a. With an automated trip planner, the passenger gives an origin, destination, and desired departure/arrival date/time. The system then returns a suggested route or routes, along with estimated departure and arrival times.

b. Classed as static information because the stops do not change from day to day.

6.1 Impact Linkages

If traveler information is to have any impact on mode choice, four conditions must hold:

1. Travelers have access to the traveler information system.
2. For “pull” systems, travelers choose to access the system.
3. Travelers find the information credible.

4. Travelers derive some benefit from having the information. This benefit may be anything from reassurance to the ability to change route and thus avoid a service disruption on the traveler's regular route.

Benefits may fall into one of several areas:

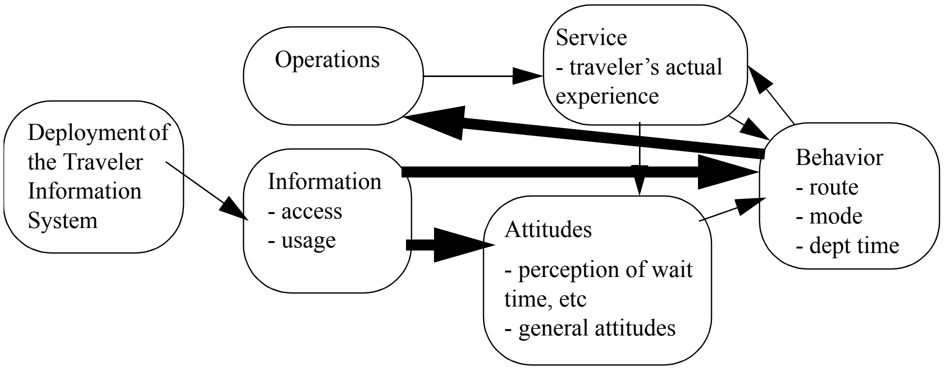
- Although the traveler does not change departure time or route, his/her confidence is increased, thus reducing the burden of the wait time, or possibly enabling the traveler to use the wait time more productively. The traveler may find it beneficial to notify people at his or her destination of the delay.
- The traveler may change route or departure time based on the information
- The traveler may change mode based on the information.

If many travelers change how they use the transit system, this may have impacts on the transit system itself. If these impacts are significant (Bottom, 2000) it may be necessary to have predictive travel information that takes into account the likely impacts on the transit system of the travel information. For example, if travelers are told to use a bus route to avoid a disruption on a subway line, and many travelers follow this advice, the bus route may become overcrowded, while the subway line may have a quicker recovery from the disruption because the backlog of waiting travelers there has been reduced.

Figure 6.1 shows the impact linkages to the various types of benefits.The three thick lines in Figure 6.1 depict linkages that will be discussed in more detail later in this chapter:

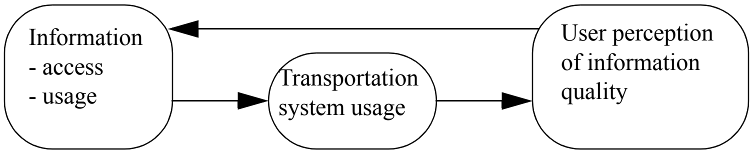
- Impact of information on traveler attitudes (perception of the system)
- Impact of information on traveler behavior
- Changes to the performance of the transit system itself, due to changes in traveler usage.

FIGURE 6.1 **Traveler Information Impacts**



With traveler information, there is also a feedback loop relating to the quality of the information provided. Transit system users will evaluate the accuracy of information that they have received. On the basis of that evaluation, they will decide whether to access or use information on the next trip. Figure 6.2 depicts this feedback loop.

FIGURE 6.2 **Feedback Relating to the Quality of Traveler Information**



Polydoropoulou and Ben-Akiva (1999) have outlined a number of steps that travelers take before they become repeat users of travel information:

- Becomes aware that travel information is available.
- Begins to think of ATIS as an option to consider when planning a trip (inclusion in consideration set).
- Uses ATIS to assess specific travel needs (choice set formation).
- Decides to try the ATIS system to assess its usefulness (trial use).

- Upon finding the ATIS system useful, makes it a habit to use the system (repeat use).

As mentioned earlier, areas that will be discussed in further detail are depicted via heavy lines in Figure 6.1. They are (1) the impact on attitudes (user perceptions), (2) the impact of static and real-time information on behavior and (3), the impact of traveler behavior on the performance of the transit system.

6.2 Impact of Improved Real-Time Information on User Perceptions

It is important to remember that the impact of information on traveler behavior and perceptions will depend on the characteristics of the traveler. For example, on-board stop announcements are likely to be much more valuable to visually impaired travelers and to travelers who are unfamiliar with the system, but may be of little value to regular commuters. On the other hand, real-time vehicle arrival time information is likely to be of value to all travelers and is thus the primary focus of this section.

6.2.1 Past Work

It is widely believed that knowing the vehicle arrival time will make wait time less onerous. This may happen via two mechanisms. Either the traveler is simply reassured that the vehicle will eventually come, or the traveler may choose to engage in another activity (such as visiting a nearby coffee shop or calling ahead to notify others of the delay).

A number of surveys have indicated that travelers like to have real-time arrival information while waiting at a transit vehicle stop. A survey conducted in Portland, Oregon (Casey, 2003) found that transit riders placed high value on having real-time transit arrival information at the bus stop (average 4.5 where 5 = highest value). Weekday respondents were more likely (67%) than Saturday respondents (48%) to rate the real-time information a "5" (highest) on the value scale. In northern Virginia, ITS applications, including real-time information, were viewed favorably by transit riders (Conklin, Englisher, Shammout, 2004).

In Seattle, an evaluation of the Transit Watch (Jensen et al., 2000) system found it is widely used. The feature most appreciated was real-time bus arrival information. In situations where the Transit Watch monitors informed travelers of a serious delay (more than 5 minutes), 40% of the respondents agreed that the information from the video monitors made them less worried.

Lehtonen and Kulmala (2002) evaluated a pilot project designed to provide real-time traveler information and signal priority to tram and bus lines in the City of Helsinki, Finland. Automated vehicle location (AVL) and computer assisted dispatch (CAD) systems were installed on Tram Line-4 and Bus Line-23. In addition, transit signal priority was provided on each route, and real-time schedule information was displayed at each transit stop.

Approximately half of the persons interviewed used the line daily or almost daily. 71% of the tram travelers and 83% of the bus travelers noticed the traveler information displays. The displays were regarded as useful by 66% of the tram travelers and 78% of the bus travelers. The most desirable features of the display were information on the remaining wait time, the option to choose another line, the understandability of the display, and knowing if an expected vehicle had already passed so the rider could make use of remaining wait time.

The ITS Impacts Matrix (accessed in 2003) indicates that an opinion survey in Turin, Italy, regarding the provision of next-stop information on board transit vehicles revealed that 75% of customers found the system useful.

In London, England, a survey of travelers using London Transport's COUNTDOWN system directly addressed perceptions of wait time and monetary valuation of the information. 82% said information displayed was acceptably accurate, 64% believed service reliability improved, 83% said time passed more quickly knowing that the bus was coming, and 68% said their general attitude toward bus travel improved.

Do these changes in perceptions lead to increased ridership? The evidence is sketchy. Average traveler valuation of COUNTDOWN was in the mid 20-pence range, or about 53% of the average fare (FTA, 1995). This translates to \$0.35 - \$0.40. Cash revenue has reportedly increased by 1.5% on the London Transport bus routes that have COUNTDOWN (Countdown, 2003). However, a stated willingness to pay does not necessarily imply a specific ridership change.

The aforementioned implementation in Helsinki also included a traveler survey: 16% of tram travelers and 25% of bus travelers reported that they increased their use of the line/route because of the real-time information displays. Based on a cross-section of test ride observations, in-vehicle studies, and ticket sales information; the pilot project increased the number of tram travelers by 0-2%, and increased the number of bus travelers by 10-12%. However, this project involved both the use of signal priority and real-time information; thus it is difficult to determine the part of the ridership increase that was due to the provision of real-time information.

6.2.2 Information Accuracy

Information accuracy is of significant concern. Anecdotal evidence indicates that errors in real-time information may fall into one of three major categories:

1. The system "knows" about the arriving vehicle, but mis-estimates its arrival time. A "countdown" prediction for vehicle arrival may be first made when the vehicle is still 10 – 30 minutes away from a stop. During that time, the vehicle may experience unusual traffic or dwell time conditions, thus arriving the stop at a time different from that predicted. For example, in Portland, Oregon, the first countdown prediction (15-30 minutes away from the stop) showed that only 53% to 72% fell within 2 minutes early or late of the time the bus actually arrived at the stop.

2. The system does not have the correct status of the arriving vehicle, and therefore either misses the vehicle entirely in its prediction, or predicts a vehicle that will not in fact arrive. Consider, for example, a real-time next bus arrival prediction that bases its predictions on buses operating on a specific street with a specific route/destination on the headboard. If the next bus to arrive at a stop is currently deadheading (traveling without passengers) along another street, the system may miss it. On the other hand, a bus that is running express (presumably due to a service disruption) may be incorrectly reported as due to arrive at a local stop, when in fact it won't make the stop.

3. In the case of major disruptions, accurate information on the duration of the outage may not exist. The nature of many delays (medical emergency at a station, vehicle breakdown) makes their duration difficult to predict. Unless the

information is actionable (i.e., is specific enough so that travelers can make alternate travel plans if appropriate) its only value will be a limited reassurance value.

Evidence from analysis of information systems on highways indicates that significant inaccuracy may negate most of its value to travelers. Toppen and others (2004) found that for Los Angeles freeway data, travel time prediction error had to be below 14 – 21% for the information to have any value. Other studies that considered the user perceptions of information accuracy in the context of highway ITS include Madanat et al. (1995), Hato et al. (1995), and two studies by Kantowitz et al. (1997).

6.2.3 Incorporation in a Demand Model

To the best of our knowledge, no one has formally incorporated improved traveler perception of wait time into a demand model. One could hypothesize, however, that the effect of the improved information is to reduce the coefficient for wait time, perhaps so that it becomes 1.5 times the value of in-vehicle time, rather than twice the value as is typically assumed. In urban travel models, the cost coefficient for travel time is typically 20 – 30% of regional average income (wage rate) (See Martin, NCHRP Report 365, 1998). Where the average annual income is $50,000 (~$25/ hour), this corresponds to a value of in-vehicle time of approximately $0.10 / minute, or $6 / hour. The cost of waiting would be reduced as follows:

TABLE 6.2 Wait Time Costs

Wait Time (minutes)	Original wait cost at 2 x IVTT $0.20 / min	New wait cost at 1.5 x IVTT $0.15 / min	Difference ($)	Difference (in minutes of IVTT)
5	$1.00	$0.75	$0.25	2.5
10	$2.00	$1.50	$0.50	5

These differences are in the same order of magnitude as the valuation determined in the survey of London Transport travelers.

6.3 Impact of Improved Static Information on Traveler Behavior

The previous section discussed the impact of improved real-time information on traveler perceptions of the transit system, with a primary focus on traveler perception of wait time. The next two sections discuss the impact of improved information on the traveler's actual usage of the system, including the traveler's arrival time at a stop and the path through the transit system that the traveler chooses. This section discusses the impact of improved static information, such as schedules and routes. The next section discusses the impact of improved real-time information. In the past few years, information on transit vehicle schedules and routes has become available through three new channels:

- Automated telephone information
- Schedules and routes on the Internet
- Trip planners

6.3.1 Information Availability

For travelers to use a transit service, they must be aware that it exists, and must be able to obtain enough information to use it effectively. There are several ways to transmit basic information about the availability of service:

- Paper schedules and maps
- Information telephone number
- Schedules on Internet
- Trip planners
- Roadside signs
- Signs and schedules posted at transit stops.

The importance of such information varies by the type of traveler trip and the type of service. Travelers planning a home-to-work trip that will be repeated many times will logically be willing to go to more effort to find the best transit route than travelers planning an occasional trip. This is because, for example, it is worth spending 10 minutes to find a route that saves 5 minutes on a trip that will be repeated hundreds of times. It is not worth spending 10 minutes to find such a route on a trip that will be taken once. Therefore, convenient information is more important for those routes that serve many occasional travelers. Similarly, convenient information is more important for infrequent services, because for an infrequent service it is not enough to know where the route goes; the wait time will also be greatly reduced if the traveler knows the current schedule.

6.3.2 Past Work

There is little understanding of the quantitative impacts of improved availability of this type of traveler information. As a recent report on transit ridership (Charles River Associates, TCRP Report 27, 1997) states, “Unfortunately, while a range of transit agencies have adopted these or similar [information dissemination] programs, almost none of them appears to have any information on the impact of these services on transit ridership.”

Other available literature suggests that the availability of schedule information is important to travelers. A survey in Ventura County, California, (Inside ITS, 1998) indicated that most of the respondents (56%) would not have made a transit trip without pre-trip information. More recently, a survey in San Jose, California, (Dahlgren and Morris, 2004) indicated that while travelers at bus stops would like to have real-time information, simply having the schedules posted is even more important. Travelers viewed having schedule information as even more important than having a shelter at the bus stop.

Routes (Rail, omnibus, underground travel enquiry system) is a computerized route planning system used by London Transport (LT). Operators respond to customers’ queries on transit information. 80% of callers made the journey they asked for information about. Of these, 38% changed their route based on information received from the operator at LT and 13% made a trip that they would not otherwise have made by public transport (ITS Impacts Matrix, accessed in 2003).

An indirect impact of improved information is improved productivity for the transit agency, thus freeing up resources that may then be used for other things. The ITS Impacts Matrix listed several examples of such impacts:

- Newark, NJ - New Jersey Transit's telephone automated transit info system reduced caller wait time from an average of 85 seconds to 27 seconds, and the caller hang-up rate from 10% to 3%

- Minneapolis, MN - Metro Transit reduced its training program for new customer service call center agents from 8 weeks to 5 weeks after the agency implemented an automated transit trip itinerary planning system.
- Rochester, NY - Rochester-Genesee Regional Transportation Authority's automated transit information system resulted in an increase in calling volume of 80%. The system handles 70% of calls and allowed 4 part-time customer information agent positions to be eliminated.

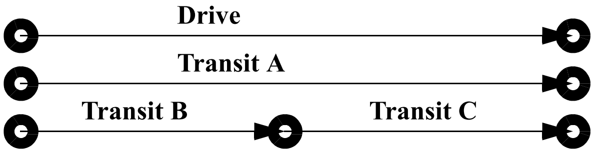
More recently, Ramming (2002) looked at the relationship between traveler familiarity with a network and route choice.

6.3.3 Impact on Demand Models

Travel demand modes generally assume that travelers have perfect knowledge of all alternatives. However, the following simple thought experiment suggests that the availability of information is important to mode choice, and that lack of information might explain at least some of the large alternative specific constants and transfer penalties that are observed.

Consider three options for traveling from an origin to a destination. The first is to drive directly from the origin to destination, the second is a direct trip on transit route A, and the third uses transit routes B and C. Figure 6.3 shows the complete set of travel options.

FIGURE 6.3 **Simple Set of Transit Options**



Suppose, further, that each of the options are equally desirable from a travel time, out-of-pocket cost and comfort standpoint. That is, given travelers who have perfect information, 50% will choose to drive and 50% will choose transit, and this last 50% will be evenly split between transit route A and transit route B-C. However, the actual mode splits depend on the traveler's awareness of the various options and are shown below. In this example, a "traveler is aware of" means "having enough information about an option so that it can be used." The travelers are segmented according to their knowledge of the various modes. It is assumed all travelers know about the Drive mode and have it as an option:

TABLE 6.3 Mode Shares

Traveler is aware of	Mode Share Drive	Transit A	Transit B-C
All modes	50%	25%	25%
Only Transit A	60%	40%	0%
Only Transit B-C	60%	0%	40%
Neither Transit A nor Transit B-C	100%	0%	0%

Suppose, further, 25% of the travelers are aware of all modes, 20% are aware of transit mode A (but not B and C), 5% are aware of transit modes B and C (but not A), and 50% are not aware of any transit modes. The resultant mode shares are shown in Table 6.4.

TABLE 6.4 Mode Splits Given Imperfect Awareness

Traveler is aware of	% of travelers	Mode Share Drive	Transit A	Transit B-C
All modes	25%	50%	25%	25%
Only Transit A	20%	60%	40%	0
Only Transit B-C	5%	60%	0%	40%
Neither Transit A nor B-C	50%	100%	0	0
Weighted Average		78%	14%	8%

Note that with imperfect information, the overall mode share of transit is lower than it might otherwise be (22% versus 50% for those travelers who are aware of all the transit options). Furthermore, the transit path that involves a transfer has a very low share (8% rather than 25%), because it requires travelers to be aware of two transit routes. If a model were to be calibrated using observed shares of 78%, 14% and 8% (from Table 6.4), it would likely have a negative alternative specific constant for transit (to account for the less than 50% usage of transit) and a high transfer penalty (to account for the lower usage of Transit B-C than of Transit A).

The above example has deliberately been over-simplified, and contains some unrealistic assumptions. It is only meant to illustrate that information availability may have a significant impact on mode choice. In reality, traveler awareness of various transit options might depend on both the trip type and the mode. In a large metropolitan area, for example, we might expect travelers to be aware of both bus and subway options for home-to-work trips, but many travelers might be only aware of the subway option for other trip types because trips of these other types are taken less frequently, and therefore they don't bother to find out about the bus options.

6.4 Impact of Improved Real-Time Information on System Usage

This section focuses on travelers using real-time information to improve the quality of their trips, either by changing departure time or route. We start with a review of the existing literature on the subject, where considerable work has been done on the highway side; less on the transit side (sections 6.4.1 and 6.4.2). We then present some elementary theoretical models of the impacts of real time information. We model both changes in passenger arrival time at a transit stop, and passenger route selection in the presence of two transit options. This provides an approximation on the wait and travel time savings that might be expected from the use of real-time information (section 6.4.3). Finally we summarize expected impacts on ridership (section 6.4.4).

6.4.1 Past Work on Highway Real-Time Information

When motorists are given real-time information, they often respond by shifting either their departure time or route of travel. Since both of these options are often available to transit users (especially in large cities, where there are multiple transit routes between two points), the literature on motorist responses to traveler information may be relevant.

Travelers Objectives

One issue is that of understanding the traveler's arrival time objective. It could be one or more of three alternatives:

- to minimize travel time
- to arrive no later than a specific time
- to arrive no earlier than a specific time.

Although demand models have typically focused on minimizing travel time, other evidence suggests that the objective of not arriving later than a specific time may be approximately twice as important as minimizing travel time (Van Vuren, Daly and Hyman, 1998). On the other hand, arriving early is valued at about half the travel time. See 4.3.1 "Value of On-time Performance" on page 70 for further discussion.

Similarly, a survey of Seattle commuters (Kuppam, Pendyala and Rahman, 1999) indicated that the "Ability to arrive on time" was more important than either "short wait time" or "short travel time." Other relevant research includes Mahmassani and Chang (1985, 1986) and Mahmassani and Stephan (1988).

These results are important, because one of the major uses of ITS information may be to avoid incidents that will result in a late arrival. ITS may provide significant benefit even if overall travel time is not reduced.

Travel Time Savings from Advanced Traveler Information Systems

In the Washington DC area, one study (Wunderlich et al., 2001) used the Mitretek Systems HOWLATE method (Heuristic On-Line Web-Linked Arrival Time Estimator) to quantify potential travel time savings and on-time performance benefits for users of advanced traveler information services (ATIS). Software applications were used to collect web-based ATIS travel time information and compile data into a model of the Washington, DC, metropolitan transportation network over a two week period (Sept-Oct 1999). Simulation was used to compare on-time reliability and travel time performance for those travelers who used ATIS and those who did not.

The simulation proceeded in two steps. First, traveler path and time of departure choices were established for a pair of travelers (ATIS users and non-users) who determined departure choices based on previous network experience. In the second step, the travel times and on-time performance of each traveler were reconstructed based on trip timing and the routes chosen in step one. Non-users were characterized as one of two types, conservative or aggressive. The conservative non-user chose earlier start times in order to buffer late arrival risk, while the aggressive user chose later start times. In-vehicle travel times and the on-time arrival performance were tracked for each ATIS user and non-user pair traveling throughout the network.

The analysis indicated that ATIS users realized substantial time management benefits from on-time arrival performance and trip predictability, but realized only marginal reductions in in-vehicle travel time. Table 6.5 summarizes the travel performance for a sample of more than 75,000 trips in the DC area during peak periods from 6:30 to 9:30 AM and 3:30 to 6:30 PM.

TABLE 6.5 Results from using ATIS during AM and PM peak periods

COMMUTER	ON-TIME RELIABILITY
Conservative Non-User	92%
Aggressive Non-User	81%
ATIS User	97%

Unusual Incidents versus Recurring Delays

In the evaluation of Seattle ITS deployments, Mitretek developed a methodology called the Process for Regional Understanding and EValuation of Integrated ITS Networks (PRUEVIIN). It combines scenario analysis, simulation and a 4-step planning model (Wunderlich et al., 1999).

Because ITS may provide the greatest benefit during unusual, rather than normal conditions, a set of 30 scenarios were developed. Each scenario represents a combination of weather, overall travel demand, and a set of incidents in the corridor.

Overall, the advance traveler information system (ATIS) experiment found a small reduction in delay (-1.5%) and in trip time variation (-2.5%). However, much of the benefit occurred in those ATIS impact with poor weather, heavy demand, freeway accidents or a combination of these factors. While these scenarios had a combined probability of 28%, they accounted for 80% of the delay reduction.

Another finding was that travelers with “high fidelity” information (such as ATIS) realized a travel time benefit while those with “low fidelity” information (such as radio and TV reports) received little or no benefit.

Lessons Learned

Key lessons from the analysis of highway advanced traveler information systems include the following:

- Minimizing travel time may not be as important to travelers as arriving on time
- ATIS provides the greatest benefit during unusual conditions. Assessing an ATIS implementation based only on average conditions may substantially understate the benefit.
- High fidelity information may lead to far more effective traveler responses.

6.4.2 Past Work on Transit Real-Time Information Impact on Traveler Behavior

In Seattle, the Transit Watch system provides real-time bus arrival information at selected locations. Users were asked about their responses to cancelled or delayed (over 5 minutes) service. About 3/4 of survey respondents recalled at least one such occasion and responded by taking different actions:

- Calling ahead to let people know of the delay (40% of users)
- Leaving the Transit Center and returning later (40% of users)
- Taking a different bus to the same destination (64% of users)
- Taking a bus to a different destination (35% of regular and 26% of occasional users)
- Using a different mode of transport (24% of regular and 14% of occasional users)

Also in Seattle, a survey of SmarTraveler users (SmarTraveler is a multi-modal traveler information system) indicated that 5 – 10% of respondents changed mode based on the improved information. In San Francisco, a survey of commuters revealed that, of those aware of traffic congestion prior to their departure, 7.1% changed mode. However, 39.3% did not change behavior because they did not believe it would help (ITS Impacts Matrix).

Hickman and Wilson (1995) analyzed the impacts of real-time traveler information on passenger travel time. They created and applied a stochastic analytic framework to a corridor in the Boston area that involves several transit paths. They found that for this corridor the benefit of real-time information was limited.

Puget Sound Transportation Panel

In 2002, the travel diary for the Puget Sound Transportation Panel included questions on the use of traveler information. Information was gathered for close to 14,000 single occupant auto trips, 8,000 rideshare trips, and 1,000 transit bus trips. For both auto and transit trips, a minority of travelers used real-time travel information. Of the travelers using information, a substantial minority learned of a possible delay. However, of those, only a minority were able to take an action, such as changing a route or departure time. Table 6.6 presents some of the counts. There appears to be less use of information on the transit side. This could be for any number of reasons:

- Information for most transit users is not available or is of low quality
- The transit system is perceived as being more reliable than the highway system; hence transit users see less need for real time information
- Transit users may have fewer alternatives for avoiding delays.

TABLE 6.6 Use of Traveler Information (Seattle, 2002)

	Single Occupant Auto		**Transit Bus**	
	Number	Comment	Number	Comment
Valid records (pre trip)	13,783		1,040	
Used information before or during trip	1,787	Main channel was radio	89	Internet, screens at transit center
Learned of possible delay	548		16	
Took action	148	109 changed route; 28 changed time	3	Time or mode change

6.4.3 Impact on Demand Models

To the best of our knowledge, no one has formally incorporated improved real-time traveler information into either a mode choice model or a transit path building model. However, the availability of real-time information could significantly change traveler arrivals at transit stops, and how transit travelers build paths on trips, and would thus result in lower trip times, and thus a greater likelihood of choosing transit.

Arrival at Transit Stop

In the absence of real-time information, it is usually assumed that for short headway routes (under 10 to 15 minutes) travelers will arrive randomly. Depending on the variability of the headway, the expected wait time is somewhat larger than 1/2 the headway. For headways longer than 10 or 15 minutes, travelers will time their arrivals in accordance with the schedule, and wait times will depend on schedule adherence. Real-time information has the potential to reduce wait times by providing more accurate estimates of bus arrival times than is provided by the schedule.

Consider a bus with a given headway whose arrival time is somewhat variable. The arrival time of this bus, for example, may follow a triangle distribution with parameters (low, mode, high) of 0, 3, and 9, yielding a mean of 4 and a standard deviation of 3.5. Expected wait times are determined for four types of travelers (cases 1 through 4):

1. Those arriving randomly, without knowledge of the schedule. In this case wait time follows the Osuna/Newell formula (See page 71) and is somewhat larger than 1/2 the headway.
2. Those having schedule information and timing their arrivals to minimize expected wait time.
3. Those with low accuracy real-time information (Bus arrival follows a triangle with parameters 0,2,7) and timing their arrivals based on that information.
4. Those with high accuracy real-time information (Triangle with parameters 0,2,4) and timing their arrivals based on that information.

Table 6.7 shows the expected wait times in minutes for various headways ranging from 6 to 30 minutes.

TABLE 6.7 **Expected Wait Time for Various Headways (minutes)**

Headway	1. Random Traveler Arrivals	2. Schedule information only	3. Low accuracy real-time information	4. High accuracy real-time information
6	3.29	3.11	2.52	2
8	4.22	3.4	2.7	2
10	5.18	3.54	2.81	2
12	6.15	3.62	2.95	2
15	7.62	3.73	3	2
20	10.1	3.91	3	2
30	15.1	4	3	2

Several observations can be made from this table:

- As headways exceed 10 minutes, there is a substantial advantage to timed (cases 2,3,4) rather than random (case 1) traveler arrivals.
- As the headway becomes shorter, the penalty for missing the bus becomes lower. Therefore, travelers can reduce overall expected wait time by arriving at the bus stop a bit later. This is why the expected wait times are somewhat lower for short headways in cases (2) and (3).
- The advantage of real-time information over schedule information is greatest when (a) the service is unreliable (the schedule information is inaccurate) and (b) the real-time information is accurate.

- Availability of accurate real-time information may cause travelers to shift from random arrivals to timed arrivals. Consider the case of the 12-minute headway in Table 6.7. Randomly arriving travelers have a 6.15 minute wait time, and travelers with the schedule have a 3.62 minute wait time, a difference of about 2.5 minutes. With this small difference, the traveler may find it is not worth the effort to time his or her arrival at the stop. However, with accurate real-time information, the wait time drops to 2 minutes, a difference of about 4 minutes. In this case, the traveler may find it worthwhile to time his or her arrival.

Path Choice

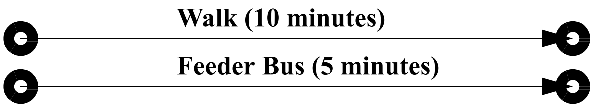
Travelers may also reduce travel time by choosing a “second best” path through the transit system, when it appears that the wait time for the “best” path will be excessive. Here are two examples:

- A 1/2 mile journey where the choices are to drive, walk, or take a bus with an irregular 10 – 15 minute headway. Given the uncertain and potentially large wait time for the bus for such a trip, most riders would choose to drive or walk. However, with real-time information, riders who can see that a bus is due within 5 to 10 minutes may choose the bus.
- A traveler who lives 1/2 mile from a subway station but chooses to walk because the feeder bus service is unreliable. Similar to the previous example, real-time information on the feeder bus may make it more attractive. This may impact transit access modeling, where it can no longer be assumed that someone originating within 1/2 mile of a premium transit node (such as subway) will always walk to that node.

These examples, and others, can be generalized as the choice between a “best” and “second best” option. In this case, the best option might be an express bus or a bus that goes to the travelers doorstep, while the second best option is a local bus, a bus that goes within a few blocks of the traveler’s destination, or walking. (Walking can be viewed as a slow bus with extremely frequent service resulting in a wait time of zero.) What does the traveler do when the “second best” option arrives at the stop? Is it better to use the second best option, or to wait some uncertain amount of time for the best option to arrive?

Consider the following simple example with enroute travel times of 10 minutes for walking and 5 minutes for riding the feeder bus (Figure 6.4):

FIGURE 6.4 **Walk vs. Feeder Bus**



Under Optimal Strategies for transit path building, the traveler does not take a predetermined route from origin to destination. Rather, route choices are made at stops along the way. In the absence of real-time information, there are two possible strategies for the above trip:

- Always take the bus
- Always walk, unless the bus is at the stop

The chosen strategy depends on both the wait and enroute times for the options. If the expected wait time for the bus were less than 5 minutes (assuming in-vehicle and wait time are valued equally) the traveler would wait for the bus. If the expected wait time for the bus were greater than 5 minutes, the traveler would walk.

With real-time information, the traveler can improve his decision based on the forecast wait time for the bus. For simplicity, the following analysis makes the following assumptions:

- Buses are equally spaced with an expected wait time equal to 1/2 headway
- Travelers place equal value on wait and travel time and thus are simply seeking the minimize their sum.

Four scenarios are presented for consideration:

1. Bus headway of 4 minutes, with expected wait time of 2 minutes. In this case, it is always worth waiting for the bus. Real-time information would not enable the traveler to change to a better route, since the bus (even with a maximal wait time of 4 minutes) is always the faster option.
2. Bus headway of 6 minutes, with expected wait time of 3 minutes. Under optimal strategies, it is worth waiting for the bus. However, with real-time infor-

mation, the traveler will choose to walk if the posted wait time for the bus is over 5 minutes. This will occur 1/6 of the time.

3. Bus headway of 10 minutes, with expected wait time of 5 minutes. In the absence of real-time information, the traveler would be indifferent between walking and waiting for the bus. With real-time information, the traveler would walk when the forecast wait time is over five minutes and would wait otherwise.
4. Bus headway of 20 minutes, with expected wait time of 10 minutes. Under optimal strategies, the traveler would walk. With real-time information, the traveler would walk most of the time, but would take the bus if one was forecast to arrive within 5 minutes.

Figure 6.5 shows the expected wait + travel times, with and without real-time information. The area in gray shows the expected savings in wait + travel time in the presence of real-time information. There are three distinct regions in this graph:

- Bus headway less than 5 minutes. In this case, the best strategy is always to wait for the bus. Therefore, the expected wait + travel time is the 1/2 the bus headway plus the 5 minute travel time on the bus. This strategy does not change if real time information is available.
- Bus headway is between 5 and 10 minutes. In this case, the optimal strategy in the absence of real time information is to wait for the bus. With real-time information, however, it may sometimes be better to walk. The difference in expected travel+wait times becomes greatest when the bus headway is 10 minutes.
- Bus headway is longer than 10 minutes. In this case, the optimal strategy in the absence of real-time information is to walk, for a total travel time of 10 minutes. However, if real-time information is available, it may sometimes be better to wait for the bus (if one is due to arrive within five minutes). However, as the headway for the feeder bus increases, it is less likely that one will arrive within 5 minutes, therefore the expected improvement in travel time becomes less.

FIGURE 6.5 Expected Time Savings from Real-Time Information

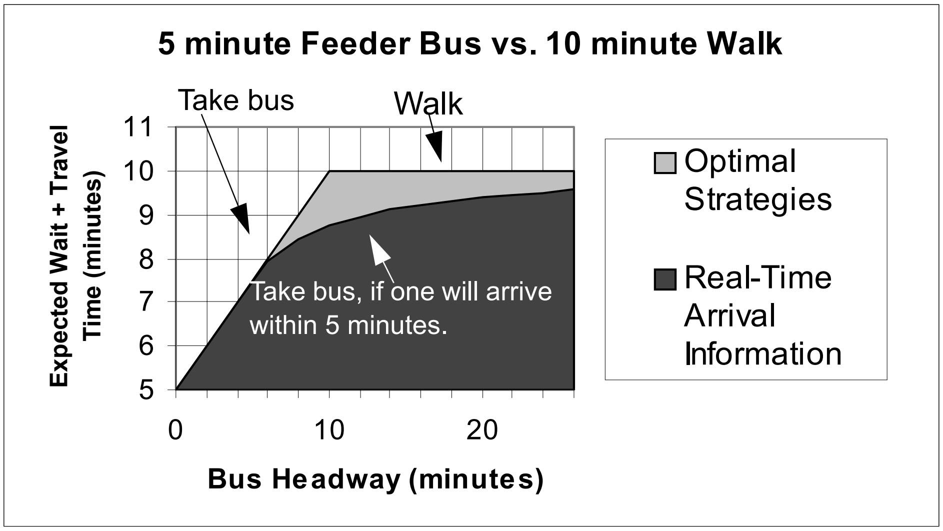


Figure 6.5 indicates a maximum difference in wait/walk time of about 1 1/2 minutes, which occurs when the bus headway is 10 minutes. However, if bus service is not reliable (so that the possibility exists of waiting for more than one headway) the difference will become larger. Therefore, a system that does nothing more than inform travelers of major disruptions may have significant value. Also, if travelers place a high value on an on-time arrival, the benefit of real-time information will also become more significant. On the other hand, if the real-time arrival information is not accurate, the benefit will be less.

To summarize, it appears that the benefits of real-time information are greatest when five conditions hold:

- There are both “best” and “second best” options available.
- It is likely that the “second best” option will arrive at the boarding stop first. (When the second best option is to walk, this is almost always true, since walking can be viewed as a slow transit vehicle with zero headway.)
- The difference in utilities between the best and second best options is substantial, and similar in magnitude to the expected wait time for the best option. (In the previous example, the difference in utility between the best and second best

options is 5 minutes of travel time. The benefit of real-time information is greatest when the best option has a headway of 10 minutes and thus an expected wait time of 5 minutes.)

- There is a substantial and uncertain wait time for the best option.
- The real-time information is accurate and thus greatly reduces the uncertainty in the wait time for the best option.

6.4.4 Overall Impacts on Ridership

No impact has been documented for static traveler information systems. For real-time systems, assumed impacts have ranged from 0 to 5%. For example, in a system with 20% mode share, the mode share would increase to 21%. In Boston, the Central Transportation Planning Staff had assumed no measurable ridership impact for the traveler information improvements in the Program for Mass Transportation (2003). The reason for this conservative assumption was an absence of credible impact data. In San Francisco, the Muni Short Range Transit Plan Amendment (2003) assumed a 5% impact, based on "data from several European peers." Table 7-2 in the 2000 Benefits Assessment for APTS assumed that advanced traveler information systems would result in a 1 – 3% ridership increase (FTA, 2000).

Are these figures reasonable? Consider a transit trip with a 5 minute expected wait time where either (a) the coefficient of the wait time in the mode choice model is reduced from 0.05 to 0.04 or (b) the actual wait time is reduced by one minute. Both of these changes reduce the wait time term by 20% and so should have exactly the same effect. With a 20% original mode share for transit, what would be the change in mode share? The incremental logit formulation gives the probability of choosing transit as

$$P_{t\_new} = P_{t\_orig} \exp(\Delta u_t) / \ \Sigma P \exp(\Delta u) \ \text{(over all modes)}$$

where

P_{t_orig} = the baseline probability (share) of using transit

P_{t_new} = the revised probability of using transit

Δu_t = the change in utility for transit

For these two cases, the new mode share is shown in Table 6.8:

TABLE 6.8 **New Mode Shares**

	Original	**Case (a)**	**Case (b)**
Wait Time Coefficient	-0.05	-0.04	-0.05
Wait Time (min.)	5	5	4
Wait Time Term	-0.25	-0.20	-0.20
Δu_t	N/A	0.05	0.05
Original Mode Share	20%		
P_{t_orig} exp(Δu_t)		0.210	0.210
Σ P exp(Δu)		1.010	1.010
New Mode Share		20.8%	20.8%
% Change in Mode Share		4%	4%

This analysis indicates that the 1 – 3% ridership increase assumed in the Benefits Assessment is plausible, provided, of course, that any real-time information supplied is accurate enough to reduce waiting times. This is, obviously, a smaller ridership impact than would be expected with a new service (such as a new express bus route), but it is significant.

6.5 Impact on Supply

On the highway side, it has been acknowledged that traveler information will have an impact on the performance of the roadway network. During peak periods in urban areas, freeways and major arterials are often running at or near capacity. Since traffic volumes are near the capacity of the roadways, a reduction in capacity (such as that caused by an accident) or an increase in traffic can result in major delays, delays disproportionate to the capacity reduction or traffic increase. Use of real-time traffic information can have two effects:

- The capability to direct traffic to other routes may be of significant benefit to traffic speeds on a roadway that is experiencing congestion, and will allow quicker recovery once the source of the congestion is removed.
- At the same time, the other routes (such as arterials used to avoid freeway congestion) may be pushed well beyond capacity.

Similar issues exist for transit lines that are running at or near capacity. For example, an incident in a subway system that delays service may lead to significant crowding on subway platforms. Once the incident is cleared, the crush of travelers attempting to board will lead to longer dwell times, thus slowing recovery of service. Use of real-time traveler information to route travelers away from the affected area will have the three benefits:

- The travelers who receive the information can either chose an alternate route or alternate departure time, and will thus have a better trip.
- Subway platforms will be less overcrowded.
- Because fewer travelers will be attempting to board once the incident is cleared, service recovery will be faster.

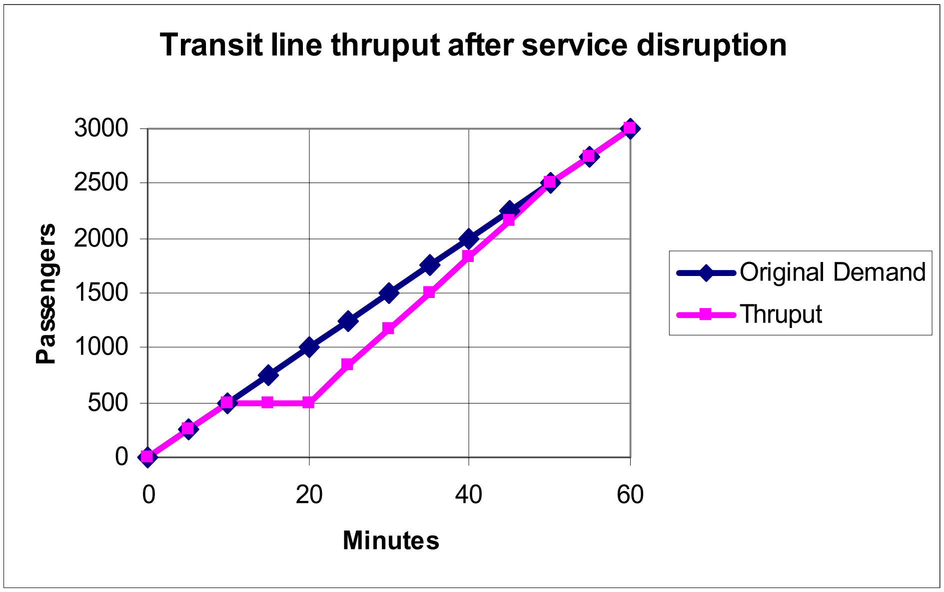
Similar to highway, there is the risk that many travelers may be routed to a lower capacity service (e.g., travelers on a subway being routed to a bus with a 15-minute headway) and will overwhelm that other service. Fortunately, the transit agency does have some capability to add capacity on short notice. This means that while it is not possible for a road agency to add a new road on a moment's notice, it is possible for a transit agency to quickly (within an hour) add service on alternate modes. For example, major subway service disruptions in large cities have been addressed through both the use of extra commuter rail service (where the subway line runs parallel to the commuter rail line) and through extra bus service.

The following example illustrates how routing travelers away from a service disruption can both greatly reduce traveler delay and speed recovery from the disruption. Consider a transit line with the these characteristics:

- Usage of 3,000 travelers per hour
- Capacity of 4,000 travelers per hour
- At time 10, there is a 10-minute service outage.

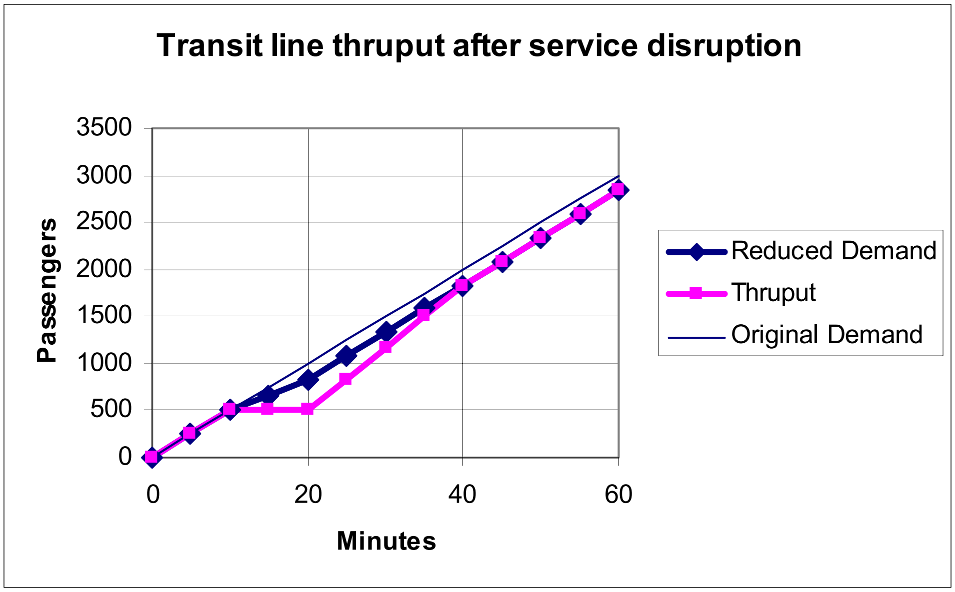
Figure 6.6 shows the cumulative travelers entering the system and the cumulative travelers carried. The area between the two lines represents the total traveler delay. Even though the service outage only lasted from time 10 to time 20, the backlog of travelers was not cleared until time 50.

FIGURE 6.6 Transit Line Cumulative Travelers after Service Disruption



Suppose that with improved traveler information, it is possible to reduce the demand per hour from 3,000 to 2,000 during the 10 minutes of the service disruption. With this modest reduction in demand, the total delay becomes much less, and full recovery from the disruption occurs at time 40, rather than time 50 (Figure 6.7).

FIGURE 6.7 **Transit Line Cumulative Travelers with Reduced Demand**



Similar to a highway, the interaction between supply and demand is most significant when the transit line is running near capacity. In this case the addition of travelers can result in a significant increase in traveler delay, while the removal of travelers can result in a significant decrease.

6.6 Conclusions and Recommendations

Current practice in mode choice modeling and network assignment makes several assumptions.

- Travelers are aware of available alternatives.
- If a premium transit mode (express bus, rail) is available within walking distance, travelers will walk to that mode and will not use any local feeder service.
- Wait time is 1/2 of the headway, but is often capped at some value.

- Traveler route choice on transit is generally based on a single best path. Where multiple paths are used, the wait times are based on the assumption that the traveler boards the first vehicle to arrive.
- Wait time is more onerous than in-vehicle time.
- Transfers are onerous, and often warrant an additional penalty.

The availability of improved static and real-time information calls some of these assumptions into question. Increased awareness of transit options that is made possible through improved static information may lead to an increased attractiveness for that transit option. Accurate real-time information may increase the likelihood of using a feeder service for short trips, may lead to changes in traveler path selection, and may make waiting less onerous.

6.6.1 What We Can Do Now

The theoretical analysis earlier in this chapter suggests that improved real-time information may have a small impact on ridership. In the case of major service disruptions, it may help the transit agency manage the disruption. At this point, any modeling of ridership impacts would be highly speculative. If modeling of ridership impacts is attempted, it should include three elements:

- Assessment of the accuracy of the real-time information
- Coverage of real-time information (which transit stops are covered)
- Impact on travelers. In current models, improved real-time information might be modeled as a small adjustment in the traveler wait time coefficient, as in Case (a) of Table 6.8. The adjustment should not exceed zero to two minutes of wait time, depending on the accuracy of the information.

The impact of improved static information is even more speculative. Although surveys indicate that travelers view static information as being extremely important, insufficient evidence exists to justify specific adjustments to planning models.

Reasonableness Tests

As stated earlier, the impact of real-time information is not likely to exceed a few minutes of wait time. Therefore, one would expect any change in transit mode share to be limited to a few percentage points (e.g. mode share increases from 30 to 31%, a 3% increase).

6.6.2 Improving Current Practice

Three areas of modeling may be influenced by improved traveler information:

1. Network construction. In some cases it is assumed that travelers will walk to a premium mode (rail, express bus) even though a non-premium mode (local bus) is located close by. Improved information may make use of the local mode more likely for short trips. If travelers know that the wait time for a feeder bus will be extremely short, they may choose to ride it rather than walking.
2. Transit path building. The path building algorithms now in common use (single best path, optimal strategies, pathfinder) assume that travelers either pick a particular transit path at the outset or choose paths based on the first vehicle to arrive. The availability of real-time information indicates that more sophisticated strategies may be possible, and that use of these strategies may result in a reduction in traveler wait time.
3. Mode choice. The availability of real-time information may influence both the actual traveler wait time and the perception of the wait time. The improved availability of static schedule information may make transit more attractive, especially for non home-based and non-work trips. One could conceive of two changes to models:
   - A new parameter indicating the likelihood that a potential traveler knows enough about an alternative to use it. This could replace some of the alternative-specific constant and would presumably be different for bus and rail.
   - Changes to both the parameters for wait and transfer times (wait time may become less onerous) and the actual assumed wait and transfer times.

There is also an ongoing need to evaluate the accuracy of information supplied to travelers.

Filling the Gaps

Areas for further research include the following:

1. What is the impact of static information availability on mode choice? Might a higher alternative specific constant for bus (vs. rail) be partially explained by the traveler's lack of knowledge of the bus service? Possible approaches to investigate this question include the following:

- Identify the relationship between improved information availability (web sites, posting of schedules at stops) and ridership.
- Identify case studies of efforts to make transit more visible.

2. What is the value of real-time information in addressing major service disruptions, as opposed to "routine" service irregularities? Research on the highway side indicates that it is in addressing disruptions that real-time information may add the most value. Questions include

- How often do major service disruptions occur?
- How effective are transit agencies at giving travelers guidance when they do occur?

3. How accurate is the real-time information that is supplied, both in the case of routine service irregularities and in major service disruptions? How does the bus arrival time as predicted by the real-time system compare with the bus arrival time as predicted by the schedule?

4. How do travelers make use of real-time information? Are they using it to engage in more dynamic route selection strategies? What impacts might this have on path building?

5. How much do travelers value real-time information? A possible approach to this question might be to equip some (but not all) bus stops on a system with real-time information, and then examine how many travelers shift to the bus stops that have the real-time information available. Presumably, these travelers are making the tradeoff that the availability of real-time information is worth some extra walking. This is a tradeoff that can be quantified.

6. When traveler information is explicitly considered, how might other parameters (such as the alternative specific constant, wait time, transfer time, transfer penalty) in demand models change?

Traveler information is a rapidly evolving area. If experience from highway traveler information systems is any indication, we can expect the quality and quantity of real-time information to continue to improve. Given the rapid evolution, it is hard to predict ridership impacts, but the limited evidence available suggests that the impact may be similar to that of removing several minutes of in-vehicle time.

CHAPTER 7 Electronic Fare Collection

This chapter discusses the impacts of electronic fare collection (EFC) systems for transit on the planning process and contains five sections:

- Impact Linkages
- Impact on Transit Service (Dwell Time)
- Use of Archived EFC Data for Transit Planning
- Impact on Ridership
- Conclusions and Recommendations.

EFC systems may be categorized by both the type of technology used and the passenger market segments that use the system. Two technologies are primarily used:

- Magnetic swipe cards or credit cards
- “Smart” cards that can store value or other information on an embedded chip. Types of smart cards include contact cards (that typically must be inserted in a slot) and contactless cards (that need only be passed near the unit).

Market segments may include the following:

- Occasional passengers

- Frequent passengers paying on a per-trip basis
- Frequent passengers using an unlimited use pass
- Transferring passengers.

A transit system may use a mix of electronic and manual fare payment means. For example, one major system in the United States uses three means of fare payment on buses:

- Cash: Exact change in the farebox
- Monthly passes: Pass with magnetic stripe swiped through the fare box
- Weekly passes and transfers: Card shown to bus operator.

When assessing the benefits of electronic fare collection, it is important to understand the means of fare payment being used in the legacy systems. For example, on a system where most peak period travelers use monthly passes, a switch from cash to stored value cards for occasional travelers may have little impact on overall boarding times during the peak period.

7.1 Impact Linkages

Impact linkages show the connection from a technology implementation to the resulting benefits. An electronic fare collection system has a number of impacts (Figure 7.1):

- The electronic media enable collection of detailed data on system usage, including linked trips (because it is possible to match the use of a particular fare card on one vehicle with its subsequent use on another vehicle). Thus, it is possible to improve service planning without the need for expensive surveys.
- The electronic media may help to reduce fare collection costs and theft of cash, by reducing the amount of cash collected.
- Use of electronic media may reduce fare evasion (e.g., use of slugs for tokens).
- When in-vehicle fare collection is used (typically, on buses), electronic media may reduce dwell time at stops since an EFC payment can be faster than a cash fare payment. With EFC, it is possible for the fare collection system to check the validity of a transfer. This reduces the vehicle operator workload. Faster

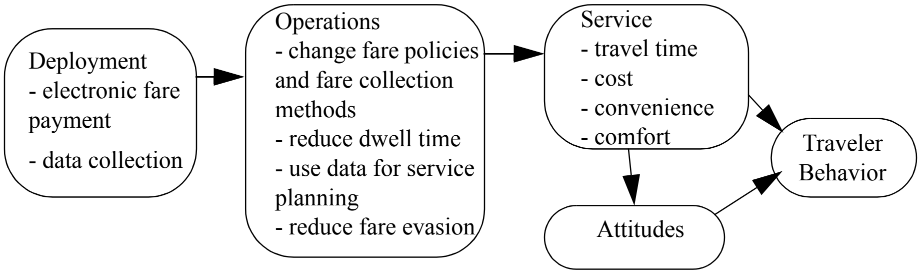
fare collection reduces in-vehicle travel time (IVTT), thus making the service more attractive to passengers and reducing operating cost per mile (because the buses are running faster).

- Use of electronic media may be more or less convenient for the passenger, and therefore may change the attractiveness of the service.

Electronic fare collection may also enable changes in fare policies. Changes typically include liberalization of transfer policies, and the introduction of inter-agency transfers. These changes may increase the attractiveness of transit, by making certain trips both less costly and more convenient for the user.

An electronic fare collection system does not provide additional information directly to travelers, so the traveler information box is not shown.

FIGURE 7.1 Electronic Fare Collection Impacts



The next two sections discuss the impacts of EFC on both ridership and passenger boarding times.

7.2 Impact on Transit Service (Dwell Time)

In situations where fare collection is on-board the vehicle, it is thought that EFC may improve service by enabling faster passenger boarding. The 1st (1999) and 2nd (2003) editions of the Transit Capacity and Quality of Service Manual (TCQSM) give default passenger service times for various fare collection methods, while the 2nd edition also offers a range of passenger service times (Table 7.1). Note that the service times from the 2003 edition are considerably longer than those from the 1999 edition.

TABLE 7.1 Passenger Boarding Service Times, from TCQSM

	Passenger Service Time for Boarding (seconds / passenger)		
	1st Edition	2nd Edition Range	2nd Edition Default
Pre-payment	2	2.25 – 2.75	2.5
Single ticket/token	2.6	3.4 – 3.6	3.5
Exact change	3	3.6 – 4.3	4.0
Swipe or dip card	-	4.2	4.2
Smart card	-	3.0 – 3.7	3.5

It appears from Table 7.1 that EFC technologies by themselves offer little advantage in terms of boarding time. However, three other factors should be considered when assessing whether there is a boarding time advantage to EFC:

1. Does the cash fare payment involve paper currency?

In 1990, Marshall et al. presented an exponential model based on observations of express bus boardings in New York City. Their model indicates that overall dwell time will increase by a factor of approximately 1.5 when dollar bills are accepted. Dwell time per passenger (with between 10 and 30 passengers boarding) was 3.3 – 4 seconds where dollar bills were not accepted[1] and 5 – 6 seconds where dollar bills were accepted. Therefore, it is possible that with the increased use of paper currency, cash fare payment may be taking longer than even the 4 seconds given in the 2nd edition of TCQSM.

The 3-second boarding time in the first edition of TCQSM was based on research that was conducted a number of years ago, when many bus fares were less than one dollar. With fares of 50 cents (2 coins) and 75 cents (3 coins), cash fare payment does not take very long. However, as fares have increased to more than 1 dollar, the time required to pay a cash fare increases because either (a) paper cur-

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[1] These were express routes with a fare of $3.50. Therefore the number of coins needed is higher than is typical for local service, ranging from 5 (3 subway tokens and 2 quarters) to 14 (all quarters).

rency is being handled (it takes longer to put a dollar bill into a fare box than a coin) or (b) more coins need to be used.

2. Even without EFC, what steps are being taken to reduce the number of cash fare payments?

Many large transit agencies in the United States are already taking steps to lessen the use of cash fare payments on their bus systems[2]. Discounted tokens are offered by the San Francisco Municipal Railway, Los Angeles County Metropolitan Transportation Authority, and the Southeastern Pennsylvania Transportation Authority. Discounted fare cards are offered by New York City Transit and the Chicago Transit Authority. The Massachusetts Bay Transportation Authority and other transit agencies offer weekly and monthly passes at a substantial discount. Therefore, if one computes the benefit of EFC by assuming the previous system is exact fare cash payment with coins and bills, one is likely to overstate the benefit of EFC.

3. As EFC technology becomes more mature, how will service times change?

It is logical to expect that service times using EFC will drop as the technology matures. This is because we can expect that EFC manufacturers will find ways to make the systems easier to use. Furthermore, we can expect a decrease in service time as passengers become more accustomed to the systems.

7.2.1 Impact on Service Time: Conclusion

With the EFC service times given in TCQSM, it does not appear that EFC by itself will reduce passenger service times, except possibly on those systems where paper currency is widely used for cash fare payments. The impact of EFC on service time will depend greatly on (a) whether the majority of passengers are currently paying with cash in the fare box, (b) whether paper currency is used for fare payment, and (c) the number of coins or bills required for fare payment. Since each of these factors varies by transit agency, the impact of EFC will also vary by transit agency.

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[2] Fare policies are based on examination of transit agency web sites in late 2003. Policies for some of these agencies may change in 2004.

7.2.2 Recommended Service Time Model

As previously noted, it is common to use a mix of fare payment methods. Therefore, the following procedure is recommended for calculating base passenger boarding times for single door loading, pay on bus. It is modeled after Step 3: Determine Passenger Service Time, given in TCQSM. The procedure requires estimating the fraction of passengers using various fare payment methods. A weighted average service time is then calculated based on the service time for each passenger class (Table 7.2). Given that cash fare service times may depend heavily on the fare being charged and whether paper currency is used, a broad range for default service time is given in column 2. An example has been filled in columns 3 through 5 using values given in italics. The fractions in column 4 may vary by time of day and day of week. For example, on some systems, the majority of weekday peak period passengers may use monthly passes, while most off-peak travelers pay cash.

TABLE 7.2 Computation of Boarding Service Time (single door boarding)

1. Payment Type	2. Default Service Time (seconds)	3. Estimated Service Time (seconds)	4. Fraction of passengers using payment type	5. Column (3) x Column (4)
Prepayment	2.5	*2.5*	*5/10*	*1.25*
Single ticket/coin	3.5	*3.5*	*3/10*	*1.05*
Exact cash fare	3.5 – 5	*5*	*2/10*	*1*
Weighted average service time per boarding passenger (sum of column 5)				*3.3*

Other Measures That Impact Boarding Times

Other measures that are normally associated with Bus Rapid Transit may yield a further reduction in boarding time and thus in-vehicle travel time. They include low floor buses and proof-of-payment. According to TCQSM (2003), low floor buses should reduce both boarding times by approximately 20% and alighting times by approximately 15 – 25%. (0.5 seconds / passenger if through a single door).

Proof-of payment is a system, used extensively in Europe, where passengers may board through all doors but are expected to have a ticket in hand. Inspectors perform spot checks, and passengers without valid tickets are fined. Proof-of-payment enables use of all doors for boarding, which can significantly reduce overall boarding time.

7.3 Use of Archived EFC Data for Transit Planning

EFC provides a wealth of data that can be archived and later used to improve transportation planning (Foote, 2004):

- Boarding dates and times for bus and subway
- Boarding route for bus
- Boarding location for subway

In most of the United States, fare collection is performed only upon station or vehicle entry, not upon vehicle exit. Nonetheless, with multi-use fare cards, it may still be possible to estimate origin-destination patterns by making the following assumptions:

- Most riders begin a trip at the destination station for the previous trip
- Most riders end their last trip of the day at the same station where they begin their first trip of the day.

In New York City (Barry et al., 2002), these assumptions were tested using travel diary information, in order to determine the feasibility of using MetroCard data to estimate origin-destination volumes on the New York subway. The researchers found that both assumptions were correct for about 90% of subway users.

Data can be used in two ways:

- Identification of peak periods and locations for special events
- Identification of common trip chains (for example, bus – subway transfers)

The information provided may enable improvements in short-term service planning (for example, better deployment of service for special events). It may also improve the modeling of transit networks and path choice, because of the vastly improved information on the transfers that are actually made.

7.4 Impact on Ridership

Electronic fare collection has often been associated with an increase in ridership. However, this increase has largely been the result of new fare policies that have accompanied EFC.

In Chicago, stored-value cards and inter-modal transfers under an integrated fare system were estimated to have increased ridership by 2 to 5% (ITS Impacts Matrix). At the time the stored value cards were being implemented (1999), a number of fare policy changes were also being implemented. They included a new $20 7-day pass, a "U-PASS" program for university students, and a decrease in the price of the 30-day pass. It was estimated that of a total 3.6% gain in CTA ridership, between 70-80% of the gain was due to the new fare policies (Foote, 2000).

New York City had a similar experience with Metrocard, which was introduced in the late 1990s. Between 1996 and 2002, ridership increased 35% (Carfiero, 2003), an increase that was far greater than the modest gain in employment during that period. However, there were a number of causes:

- Due to the change in fare structures that accompanied the introduction of Metrocard, the average fare decreased by 25% (from $1.38 to $1.04) during this period. Some of the fare structure changes included free intermodal transfers, a bonus on large value Metrocards, a reduction in express bus fares, and the introduction of unlimited ride Metrocards.
- Service improved with subway mean distance between failures increasing significantly in the 6 years.
- Between 1990 and 2002, crime generally decreased.

In 1993, the Los Angeles region began testing both smart card (chip embedded) and debit card (magnetic stripe) technologies to integrate fare payment. As a result of increased service and fare coordination, inter-operator transfers increased from 0.5% to 2% of passenger trips, or 11 million passenger trips per year (ITS Impacts Matrix). However, some of this increase was the result of the introduction of Blue Line rail service, which provided many more opportunities for inter-agency transfers (Carter and Pollan, 1994).

One caution in using ridership numbers is that transit ridership in the United States is generally measured in terms of unlinked trips; that is, a subway ride followed by a bus ride would count as two trips. If transfer policies are liberalized (e.g., introducing free bus-subway transfers), the number of unlinked trips may increase significantly while the number of linked trips remains nearly unchanged. This is because subway passengers who were formerly walking to their final destination may now be taking buses.

To conclude, the use of electronic fare collection can facilitate fare policy changes and has often been accompanied by policy changes. The policy changes can have significant impacts on ridership and must be accurately represented in demand models. However, it is not clear that the convenience of EFC by itself will result in an appreciable change in ridership.

7.5 Conclusions and Recommendations

EFC provides many benefits. It may enable changes in fare policies, provide data to improve service planning, reduce fare evasion, and reduce transit agency fare collection costs. However, without a change in fare policy (such as a proof-of-payment fare collection system with boarding through all doors) it does not appear that EFC by itself will reduce dwell times. Further, it does not appear that the convenience aspect of EFC by itself will lead to an increase in ridership.

7.5.1 Improving Current Practice

Although there is little evidence that EFC directly influences ridership, the presence of EFC presents both an challenge and an opportunity to those who build planning models.

The challenge lies in correctly modeling the new fare policies that may be implemented in conjunction with EFC. Transfer policies may be liberalized, thus reducing the cost of the trip for many passengers. This change in fare must be accurately modeled.   The transit agency may go to a proof-of-payment system that enables all doors to be used for boarding. Such a change may lead to substantial improvements in passenger boarding times, and therefore, to in-vehicle travel time.

The opportunity lies in using archived EFC data to better understand system usage. EFC provides a wealth of data on passenger movements that can be captured and used to improve the quality of modeling. For example, a transit agency can gain a much better understanding of what transfers are actually being made by passengers. This data can be used to improve both access coding (how many people are actually using the bus as a feeder to the subway?) and model calibration.

Although there is no justification for arbitrarily adjusting model parameters based on the presence of EFC, there are three things we can do to improve our understanding in future years:

First, ensure that the EFC system provides archival data, as discussed in the previous section.

Second, continue to perform field work on boarding and alighting times in the presence of various fare collection strategies. We can expect that boarding times will change in both the upward (as more transit agencies increase fares to more than one dollar) and downward (as EFC technologies become easier to use) directions. As noted earlier, the amount of time required for fare collection depends on the amount of fare being charged and how it is being collected. Since this varies from one transit agency to another, an accurate assessment of the impact of EFC may require field observation of the existing system at the transit agency in question. Further, as more agencies go to all-door boarding via a proof-of-payment scheme, the impact on boarding and alighting times should be assessed.

Finally, continue to monitor new fare policies (such as the increased use of day passes) and consider how these can be accurately modeled.

CHAPTER 8 *Combined Technologies*

In major capital investments, ITS technologies are generally combined with other improvements such as dedicated lanes, guideways, new stations, and more frequent service. Furthermore, an effort is often made to make the new service visible and attractive to prospective passengers.

The impact of some of the ITS improvements and the dedicated rights-of-way appear in the form of improved in-vehicle time (IVTT). The reduced headways appear in the form of improved out-of-vehicle time (OVTT). Both IVTT and OVTT are readily modeled. There are, however, other factors that are not typically quantified, such as improved visibility, convenience, comfort and reliability.

Earlier in the handbook, we suggested that those impacts of ITS that are not easily modeled (traveler information, reliability) might be expressed as an equivalent savings in in-vehicle time. Plausible savings from the ITS improvements were found to be the equivalent of several minutes of IVTT.

In this chapter, we examine two recent bus rapid transit (BRT) implementations in the United States, comparing their ridership numbers to ridership on the previously existing bus routes. We assess how much of the ridership change is explained by an actual reduction in travel time, and determine the in-vehicle travel time equivalent for the portion of the ridershp change that is not explained by an actual reduction in travel time.

The two BRT implementations examined are Phase I of the Silver Line in Boston and the Wilshire-Whittier and Ventura Metro Rapid services in Los Angeles.

8.1 Boston Silver Line Phase I

The Massachusetts Bay Transportation Authority (MBTA) Silver Line is a bus rapid transit line that opened in 2002. It runs for a distance of approximately 2 miles on Washington Street from Downtown Crossing to Dudley Square, in the urban neighborhood of Roxbury (Figure 8.1). Before 1983, an elevated rapid transit line (Orange Line) ran above Washington Street. This was moved about 2/3 of a mile to the west in the 1980's and the elevated structure was torn down. Between the late 1980's and 2002, bus route 49 provided the primary service on Washington Street. In 2002, Phase I of the Silver Line replaced route 49.

FIGURE 8.1 MBTA Silver Line

Since its inception, ridership on the Silver Line has grown to approximately 14,100 passengers per weekday, considerably higher than the 7,600 weekday daily passengers seen on route 49.[1] Table 8.1 lists some of the differences between the Silver Line and the prior service. Although real-time traveler infor-

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[1] At the time the 14,100 passengers per weekday was measured, the service was operating with 40-foot low floor buses, and was somewhat capacity constrained according to MBTA officials. Since then, 60-foot buses have been introduced. Therefore, ridership today may be higher than the 14,100 used in this analysis.

mation and signal priority are under development, the major ITS technology that is now operational is AVL/CAD.

TABLE 8.1 Differences between Silver Line and Prior Service

Attribute	Silver Line	Route 49
Travel Time (one way, assumed to be 1/2 of round trip)	12 - 18 minutes	~5 minutes longer
Base weekday headway	5 - 6 minutes	7 - 9 minutes
Peak weekday headway	4 - 4.5 minutes	6 minutes
Connection to Red Line	Direct at Downtown Crossing	~700 ft. walk from South Station or Downtown Crossing
Connection to Green Line	Direct at Boylston St. for southbound buses. Short walk to Park Street for all buses.	~2000 ft. walk for southbound buses. ~500 ft. walk for northbound buses.
Connection to Orange Line	Direct	Direct for northbound buses only.
Visibility	Distinctive stops Appears on subway "spider" maps Directional signs from subway stations	
Comfort/convenience	Low floor buses	High floor buses
Reliability	Probably better due to real-time operations control	
Technology	AVL is operational Signal priority and passenger information under development (as of 2003)	

In order to understand the increase in ridership, two questions must be answered:

1. Given the actual change in ridership and an assumed elasticity of in vehicle travel time (IVTT), how much of a change in IVTT would be required to fully account for the change in ridership?

2. How does this change compare with the actual difference in IVTT? The difference would represent the impact of the other factors, such as shorter headways, and improved visibility, comfort, convenience and reliability.

Table 8.2 shows the calculated IVTT allowance, given various values of elasticity. Column (a) is the assumed elasticity (Recall the value of -0.4 from the example on page 200.) Column (b) is the change in IVTT that would be required to fully explain the change in ridership. Column (c) is the actual change in IVTT (assuming passengers travel from end to end). Column (d) is an allowance for the change in wait time. The Silver Line has a headway approximately 2 minutes shorter than the former route 49. Under the assumption of wait time = 1/2 headway, this corresponds to a reduction in wait time of 1 minute. However, since wait time is generally considered to be at least twice as onerous as IVTT, the equivalent IVTT (assuming a multiplication factor of 2) is 2 minutes. The last column is the difference, and reflects the IVTT equivalent of factors such as visibility, comfort, convenience and reliability.

TABLE 8.2 **Silver Line: Calculated IVTT Allowance**

(a) Assumed elasticity	(b) Change in IVTT that would fully account for the change in ridership (minutes)	(c) Actual change in IVTT (minutes)	(d) IVTT equivalent of change in OVTT (minutes)	(b) - (c) - (d) (minutes)
-0.3	17.5	5	2	10.5
-0.4	15	5	2	8
-0.6	11.5	5	2	4.5

Two factors that may account for much of the increase in ridership include the improved connectivity and visibility in the downtown area and the use of the service as a substitute for Orange Line service.

The route 49 service only had a direct connection to the rapid transit system for northbound (inbound) buses at one station on the Orange Line. There was no direct connection for southbound (outbound) buses. To connect to the Red or Green lines, or to connect from the Orange Line to a southbound bus, a substantial walk was required. In contrast, the Silver Line has a direct connection to the Orange Line at several stations, a direct connection to the Red Line (the most heavily used of Boston’s four subway lines), and a connection to the Green Line.

All these connections have signposts from the subway stations. A recent survey of Silver Line passengers,[2] conducted between the hours of 6 AM and 3:30 PM, indicated that 31 percent of the southbound passengers accessed the Silver Line from another transit line. 18 percent of northbound passengers transferred from the Silver Line to another transit line.

As can be seen in Figure 8.1, the Silver Line runs more-or-less parallel to the existing Orange Line service, with a separation of about 2/3 mile. What the figure does not show is that virtually all of the bus routes that connect to the Silver Line also connect to the Orange Line. For example, several routes serve both Dudley Square (Silver Line) and Ruggles (Orange Line) stations. According to the aforementioned survey, some 31% of northbound Silver Line passengers transferred from a bus. Similarly, 33% of southbound passengers transferred to a bus. The vast majority of these transfers were from or to routes that also serve nearby Orange Line stations. Not surprisingly, the same survey indicated that some 29% of Silver Line passengers were former users of the Orange Line.

8.2 Los Angeles Metro Rapid

The Los Angeles County Metropolitan Transportation Authority (LACMTA) Metro Rapid is a series of bus rapid transit lines serving the Los Angeles metropolitan area. Two of the lines (Wilshire-Whittier and Ventura) are discussed here. The Wilshire-Whittier line operates in a 23-mile urban corridor running through the central business district. The Ventura line operates in a 15-mile suburban corridor connecting to a subway station. Both lines were implemented in 2000, and coexist on the corridor with local bus service.

The Wilshire service has seen a ridership increase (MetroRapid and local buses) from 63,497 passengers to 84,153 passengers. The Ventura service has seen an increase from 10,800 passengers to 13,650.

Table 8.3 shows some of the differences between the MetroRapid service and its predecessors. ITS technologies deployed include

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[2] Unpublished memorandum from Central Transportation Planning Staff to MBTA, 2/10/2004

- Transit Signal Priority with both Green Extension and Red Truncation. The bus is detected via loop detectors that are typically placed 250 feet in advance of the intersection. A mix of unconditional and conditional priority are used.
- Real-time passenger information at a limited number of stops
- Automatic Vehicle Location

TABLE 8.3 Features of Metro Rapid Services

Attribute	Improvement
Travel Time	Cut from 39 to 31 minutes on the Wilshire-Whittier line Cut from 32 to 25 minutes on the Ventura line
Visibility	Distinctive buses and stops
Comfort/Convenience	Low floor buses
Reliability	Improved
Technology	- Transit Signal Priority - Passenger Information - AVL

Similar to the analysis for Boston, we calculate the change in IVTT that would be required to fully account for the change in ridership, and then compare that change to the actual difference in IVTT. The difference would represent the impact of the other factors, such as shorter headways, and improved visibility, comfort, convenience and reliability.

Tables 8.4 and 8.5 show the calculated IVTT allowance, given various values of elasticity. These tables are similar to Table 8.2. Column (a) is the assumed elasticity. Column (b) is the change in IVTT that would be required to fully explain the change in ridership. Column (c) is the actual change in IVTT (assuming passengers travel from end to end). Column (d) is an allowance for the change in wait time. Although before and after headways were not presented in the Los Angeles report, the revenue hours of service increased on both the Wilshire and Ventura routes. The increased revenue hours of service were arbitrarily assumed to result in a 1-minute reduction in wait time, or a 2-minute equivalent change in

IVTT. The last column is the difference, and reflects the IVTT equivalent of factors such as visibility, comfort, convenience, and reliability.

TABLE 8.4 **Wilshire-Whittier IVTT Allowance**

(a) Assumed elasticity	(b) Change in IVTT that would fully account for the change in ridership (minutes)	(c) Actual change in IVTT (minutes)	(d) IVTT equivalent of change in OVTT (minutes)	(b) - (c) - (d) (minutes)
-0.3	25	8	2	15
-0.4	20	8	2	10
-0.6	15	8	2	5

TABLE 8.5 **Ventura IVTT Allowance**

(a) Assumed elasticity	(b) Change in IVTT that would fully account for the change in ridership (minutes)	(c) Actual change in IVTT (minutes)	(d) IVTT equivalent of change in OVTT (minutes)	(b) - (c) - (d) (minutes)
-0.3	18	7	2	9
-0.4	15	7	2	6
-0.6	10	7	2	1

8.3 Discussion

Even though the Boston and Los Angeles implementations of BRT are very different, and are located in cities that are very different, the computed IVTT allowances are remarkably similar. The Boston results fall approximately midway between the results for Wilshire-Whittier and Ventura. Assuming an elasticity of demand with respect to travel time savings of -0.4, and a 1-minute reduction in OVTT, the IVTT allowance ranges between 6 and 10 minutes. If the adjustment for OVTT is omitted, the IVTT allowance would range from 8 to 12 minutes.

It is important to note, however, that in both cities, substitute services are available. For Boston, it is the Orange Line, and in Los Angeles, it is other bus routes. Therefore, the elasticity might be higher in magnitude than the -0.4 that is typically assumed. With an elasticity of -0.6, the IVTT allowance ranges between 1 and 5 minutes.

Furthermore, factors other than ITS could explain at least part of the IVTT allowance in both cities. This is particularly true in Boston, where the Silver Line provides substantially improved connectivity to existing transit routes. In both cities, the BRT services were unveiled with both distinctive stops and a considerable marketing effort. On the other hand, at the time these ridership numbers were measured, the use of ITS had not reached its full potential on either service. Both services were fairly new, and it is likely that as the transit agencies gain more experience, they will be able to use AVL information more effectively to improve service reliability. In Boston, neither real-time traveler information nor signal priority were operational, while in Los Angeles, parts of the Wilshire corridor (outside the city of Los Angeles) were not receiving signal priority and real-time information was in place at only a few stops.

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APPENDIX A

Four-Step Models

Transportation models are typically used to forecast future travel conditions and to assess the impacts of transportation system changes. A proposed transportation system change may have many impacts including

- Direct impacts on the transportation system, such as improved mobility and safety
- Economic impacts, including jobs and land redevelopment
- Impacts on the human environment, including possible disruptions to local communities
- Impacts on the natural environment, including air quality impacts.

A comprehensive transportation modeling system includes supply and demand models. Transportation supply models assess the performance of a portion of the transportation system. They may range from very simple (e.g., an equation that uses traffic signal timings and traffic volumes to assess the delay at the signal) to the complex (e.g., an integrated highway/transit simulation model). Transportation demand models predict how the system will be used. Aspects of usage include what trips will be taken, where will the trips go, what modes will be chosen, and what routes will be chosen. Accurate modeling of the impacts of a major transportation system change requires that supply and demand models work together.

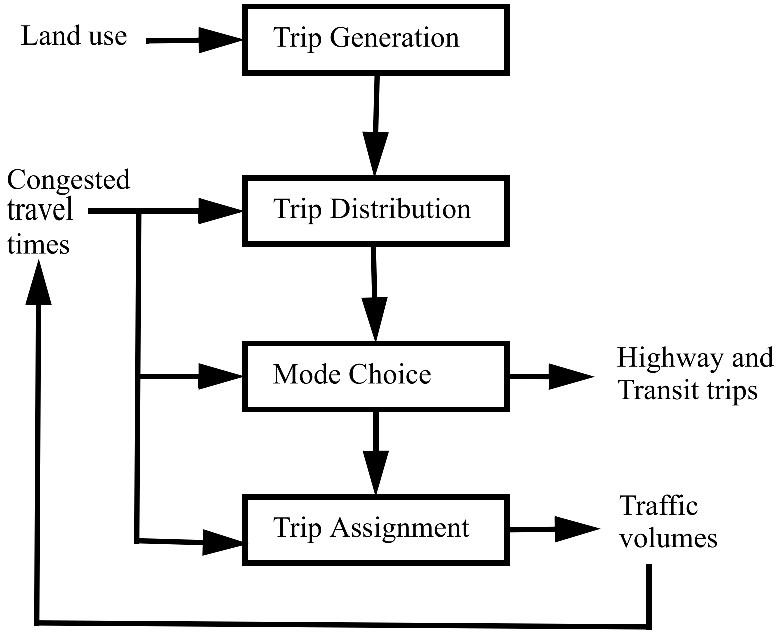
This chapter focuses on the methods currently used by metropolitan planning organizations (MPOs) to represent the transit mode in their planning models, and includes documented practices of a sample of MPOs. It includes an overview of the so-called 4-step process for modeling, the representation of transportation analysis zones, transit supply, transit demand and existing methods for analyzing ITS improvements.

A.1 Four-Step Process

The framework traditionally used by planning agencies to assess the impacts of a transportation system change involves four major steps, hence its name. The steps are as follows (Figure A.1):

1. Trip generation. After dividing the analysis area into smaller zones (often called transportation or traffic analysis zones), estimate the number of trips that will start and end in each zone.
2. Trip distribution. Connect the trip ends. This is generally done via a gravity model, where the number of trips between a pair of zones is inversely related to the distance between the zones. (e.g. for a home to work trip, a commuter is more likely to go to a workplace close to home than one that is far away).
3. Mode choice. Allocate trips among various modes, such as single occupant auto, carpool, transit, and non-motorized.
4. Assignment. Assign the traffic to the appropriate routes in the transit and highway networks.

FIGURE A.1 **Four-Step Process**



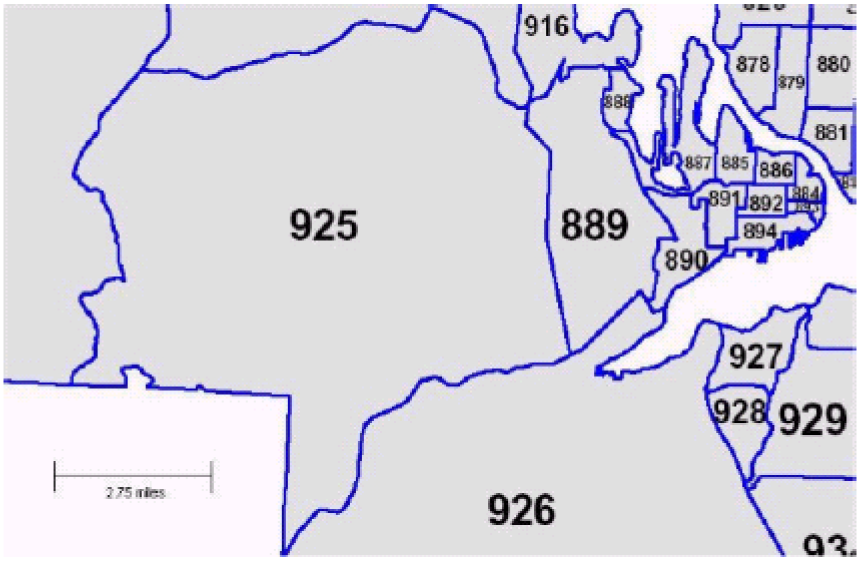
In the four-step process, the transit and highway systems are generally represented as networks. Users are modeled as flowing from an origin zone through the network to a destination zone. The supply attributes of the transportation system (travel time, cost) are captured as costs on the links.

To understand how the impacts of transit ITS might be incorporated into modeling procedures, it is important to understand three aspects of these procedures. These are the representation of origins and destinations as transportation analysis zones, the modeling of transit supply, and the modeling of mode choice. The next three sections will discuss these areas.

A.2 Transportation Analysis Zones (TAZs)

A metropolitan area may contain millions of potential origins and destinations for trips. It is impractical to model all of these potential trip endpoints. Therefore, the region is typically divided into transportation (or traffic) analysis zones (TAZs). Trip origins and destinations in a particular geographic area are aggregated into one TAZ. The size of TAZs varies greatly depending on the number of people in the area, the proximity to transit lines, and the level of interest in the area. As shown in Figure A-2, TAZs further outside of a city could be many square miles in area whereas TAZs in an urban area could be the size of a city block or smaller. Typical numbers of TAZs for a planning area vary significantly. For example, the Puget Sound Regional Council (PSRC) uses roughly 950 TAZs to model the four counties (Shohomish, King, Pierce and Kitsap) in its 2,000 square mile planning area.

FIGURE A.2 **Transportation Analysis Zones (from PSRC)**

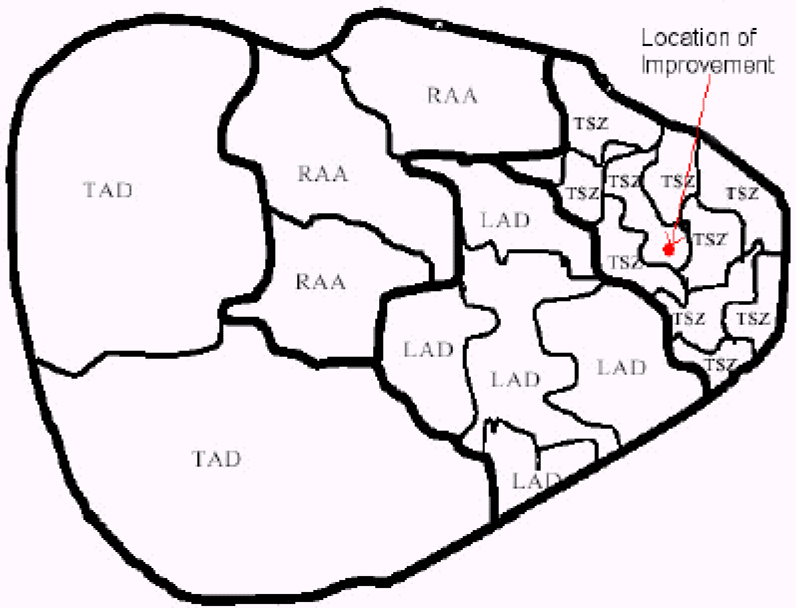


On the other hand, the North Central Texas Council of Governments uses a hierarchical structure to create TAZs (Table A.1). It is not feasible to use all of the traffic survey zones (TSZs) in a study; therefore, for a particular study different combinations of zone levels are chosen as illustrated in Figure A.3. Each of the zones selected for the a study will become a transportation analysis zone regardless of its zone level. This process of selecting zones for an analysis is handled by software that converts user defined polygons into the underlying hierarchal zones. Furthermore, equivalency tables are created that map TAZs to their constituent TSZs, which allows results for different studies to be compared and reused in future studies.

TABLE A.1 Hierarchy of Transportation Analysis Zones

Level	**Description**	**Composed Of**
Level 0	Dallas-Fort Worth Metropolitan Area	57 Jurisdictions
Level 1	Jurisdiction (JUR)	196 Transportation Analysis Districts
Level 2	Transportation Analysis District (TAD)	721 Regional Analysis Areas
Level 3	Regional Analysis Area (RAA)	2,331 Local Analysis Districts
Level 4	Local Analysis District (LAD)	5,999 Traffic Survey Zones
Level 5	Traffic Survey Zone (TSZ)	Basic Zone Unit

FIGURE A.3 Sample Combination of Zones



A.3 Transit Supply

Given that a traveler is using transit to travel between two points, transit supply modeling aims to provide an accurate representation of that trip. Four major components of transit supply modeling include 1) the construction of transit network, 2) access between traveler origins and destinations and the transit network, 3) attributes of the transit trip, and 4) building paths within the transit network.

A.3.1 Transit Networks

The first step in building a transit network is to define all the transit routes and the stops along each transit route. The stops along a route generally correspond to nodes in the various software modeling packages, and the connection between two adjacent stops will form a link in the transit network. These routes, nodes, and links have various attributes associated with them which help describe the transit network (e.g. mode, headway, capacity, fare details, transfer details, travel time, waiting time, dwell time, distance). Also, the transit network of routes that share the right of way with automobiles will overlay the highway network. Any transit modes or links that do not interact with the highway network can be defined separately.

A.3.2 Access Links

Once the creation of the transit network is completed, the modeling of the access links can begin. The access links connect the transit network to the centroids in the transportation analysis zones and typically represent drive, feeder bus or non-motorized (walk/bike) access to the transit system. Two methods will be discussed. The first creates centroid nodes to represent city block(s), buildings, or other locations that contribute to the use of the transit system (Figure A.4). Access and/or egress links are created between the centroids and the corresponding transit stops.

Although creation of these access links could be done manually, one MPO has developed a software application that automatically generates the non-transit links using a set of rules similar to those used in the manual process. Through several iterations of testing and modifying the application, the deficiencies were identified and new rules were added to correct the behavior. Some of the rules are listed below (Dallas-Fort Worth Regional Travel Model (DFWRTM): Description of the Multimodal Forecasting Process, Section IX):

> - To ensure adequate connection of each zone to all transit modes, the program does entirely separate analyses of walk-access to local and express services. The program generates for each zone one set of walk-access links to nodes served by local bus routes and a separate set to nodes served by express buses and rail lines. Thus, the program can reach beyond nearby "local" nodes to connect the zone to more distant "express" nodes or rail stations that are within the maximum walk access distance.
>
> - The program attempts to provide a wide dispersion of access links in terms of direction from the zone centroid. It avoids the generation of links connected to nodes that are near to each other, unless one of the nodes is "local" and the other is "express."
>
> - To avoid software revisions to other programs used for transit network processing and to avoid unnecessary time and cost in processing superfluous access links, the program gen-

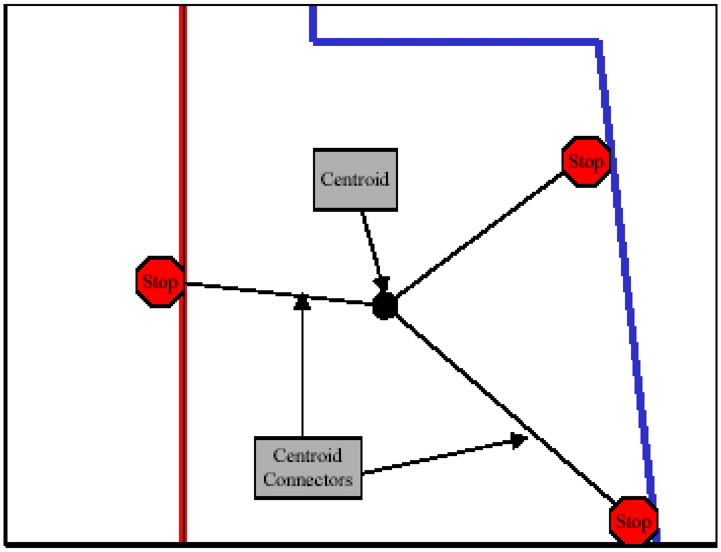
erates a maximum of four walk-to-local links, four walk-to-express links, and four drive-access links.

- A high priority for connection with a walk-access link is any stop node at which transit lines intersect. This priority arises because a single connection to an intersection node may make walk access possible to more than one transit line, reducing the need for transfers and generally increasing the accessibility of the network.

- Similarly, the program gives priority to rail stations for connection with walk access links. This priority reduces the chances that travelers from a zone have to use an unrealistically short bus trip to reach the rail station, when a slightly longer walk would bring them directly to the station.

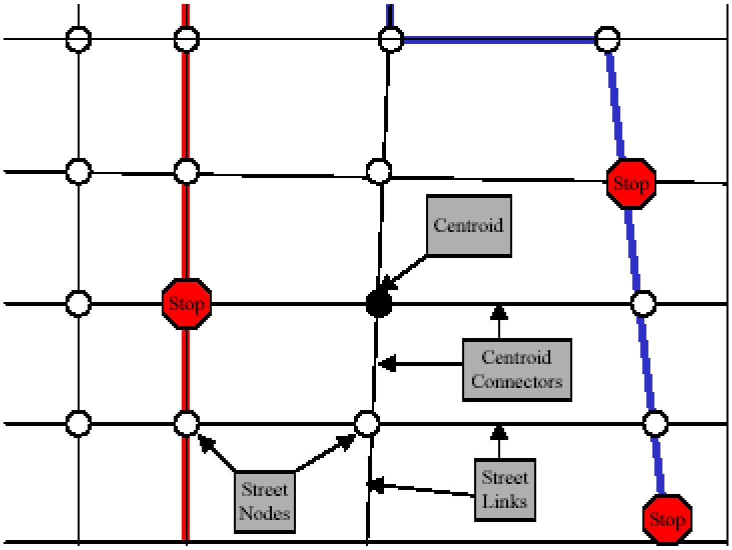
This application virtually eliminates the manual work required to build the non-transit links, and it provides results that are comparable to those generated through the manual process.

FIGURE A.4 **Traditional Representation of Transit Access Links**



The second method also creates centroid nodes to represent city block(s), buildings, or other locations; however, this method does not create links between centroids and stops. Instead, this method overlays the transit routes and stops on the street level network which includes major and minor streets (Figure A.5).

FIGURE A.5 **Transit Access Links on the Street Network**



Once these networks are combined, centroids can be created and connectors established between the street level nodes and the centroids. With this second method the representative path of a passenger would go from a centroid connector to a street level node and then to a stop along the street level links. One of the strengths of this method is that a mapping between centroids and stops does not need to be estimated. Another strength is that the estimates of the travel times and distances will be more accurate since the links mirror the existing street network rather than straight lines between the centroid and the stop. The major weakness of this method is that the number of access links that will exist in the network is quite large. Furthermore, if this method is used to represent walk access, all pedestrian links with significant potential usage should be represented, including those that are not open to motor vehicles.

Another aspect of transit access path building concerns the mode used to access transit. Modes considered typically include non-motorized (walk or bike), drive, or feeder bus. Conventions given in "Guidelines for Network Representation of Transit Access, State of the Practice Summary" (SG Associates/VNTSC,1998) include the following:

Single access for entire zone - All travelers within a zone are assumed to use a single access mode - typically represented by one or more centroid connector links that represent either walk access to a transit line or drive access to a single park-ride lot.

All or nothing by market segment - Transit access is considered to be identical for all travelers in a market segment and to connect to the transit system at a single point for all trip paths for a given ij combination. All travelers in the walk access area are assumed to walk to transit.

Multiple paths - Separated transit paths are built representing multiple choices of access mode and /or travel mode available to each market segment. This is achieved in path building by applying weighting factors to the transit travel times of specific link types so that the resulting paths are the best available for the access or travel mode being considered. The allocation of trips among the competing transit paths can then be addressed either through a separate sub-mode choice model or more commonly as choices within a nest level in a nested logit mode choice model.

A.3.3 Transit Attributes

An important step in building a transit network is determining the appropriate values for attributes of transit service once the traveler has reached the transit stop. These include initial wait time, in-vehicle time, transfer time (if a trip involves more than one transit vehicle) and the fare paid.

Initial Wait Time

For services where the headway is less than 10 or 15 minutes, it is typically assumed that passengers will arrive randomly (without consulting the schedule). If the headways are evenly spaced, the average passenger wait time in this case is equal to 1/2 of the headway. For routes with large headways (over 10 or 15 minutes), it is assumed that passengers will time their arrivals in accordance with the vehicle schedule, thus resulting in a wait time that is a fixed value and does not depend on the headway.

Several approaches are used to deal with the differing passenger behavior on long versus short headway routes.

1. Capping of wait times.

The wait time is assumed to be the minimum of two values:

- 1/2 the headway
- X minutes

In one city, the value of X is 15 minutes, implying that for services with a headway of at least 30 minutes, passengers will consult the schedule to avoid extremely long waits. An advantage of this approach is that it appears to reflect actual passenger behavior. A disadvantage is that when headways are long, it is insensitive to differences in headway. Since demand models often do not include a service frequency variable, the capping of wait times results in a model that assumes no difference between a service that runs every 30 minutes and a service that runs every 2 hours.

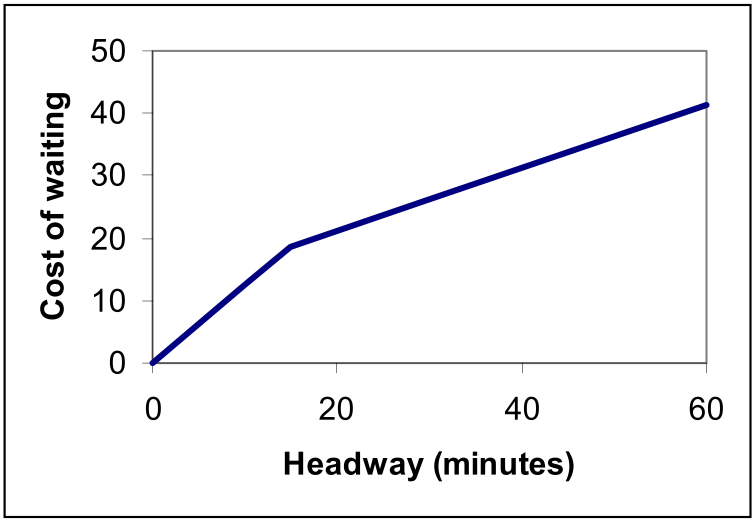
2. Bifurcated wait time coefficients.

The "cost" of waiting is modeled as the wait time multiplied by a coefficient. In this approach, the first Y minutes (typically, about 7.5 minutes) of wait time are modeled with one coefficient, while any waiting beyond Y minutes is modeled with another coefficient that is lower in magnitude. The "cost" of waiting might be modelled as follows:

$$Cost = 1.5 \cdot Min\left(\frac{H}{2}, 7.5\right) + \frac{H}{2} \qquad \textbf{(EQ 1)}$$

Figure A.6 shows the result.

FIGURE A.6 Cost of Waiting as a Function of Headway



The advantage of this second approach is that it is sensitive to differences in headways when headways are long (e.g., 30 minutes versus 2 hours), but effectively assumes that for these long headways, the marginal cost of waiting decreases.

A more accurate assessment of waiting time would require an evaluation of the following:

- Passenger behavior. Are they consulting a schedule and arriving for a particular trip, or are they just arriving and waiting for the next vehicle (without consulting a schedule)? The usual rule-of-thumb is that when headways exceed 10 or 15 minutes, passengers will consult schedules.
- Service reliability. More reliable service results in shorter waiting times. To use a simple example, consider a bus service with 6 buses per hour (headway of 10 minutes). If the headways are evenly spaced with predictable arrival times, then the passengers may learn the schedule and bunch their arrivals just before the bus arrives, thus yielding an average wait time of less than 5 minutes. If the headways are evenly spaced, but the passengers don't know the schedule, then the passengers may arrive at a constant rate. This yields an average wait time of 1/2 the headway, or 5 minutes. If service is unreliable,

with buses bunched in pairs, then the effective headway becomes 20 minutes, thus yielding an average wait time of 10 minutes.

Chapter 4 contains a more extensive discussion of passenger behavior and wait times.

In-vehicle Time

In-vehicle time is closely related to the average speed of the transit vehicle, which in turn in influenced by the following factors:

- Vehicle cruise speed
- Vehicle acceleration and deceleration characteristics
- Number of passenger stops
- Dwell time at each stop, which is influenced by the time required to re-enter traffic, vehicle door configuration, fare collection practices, and the number of passengers boarding and alighting
- Vehicle schedule. If the schedule has too much slack time, average speed may be reduced because the vehicle is consistently arriving early at timepoints, and thus has to wait.
- Congestion delay, including signal delay.

A number of techniques are used to estimate average speed. Each has advantages and disadvantages.

1. Estimate speeds based on the transit schedules

Here, the transit vehicle is assumed to run in accordance with its schedule. An advantage of this method is its simplicity. If the schedule is accurate, it captures all the factors contributing to in-vehicle time as they currently exist. This method, however, has several significant disadvantages. First, the published schedule may be inaccurate. Vehicles may be consistently late or early. Second, schedules are only available for services that are currently offered. Third, the current schedule is insensitive to changes in future conditions. Changes to the highway system may influence congestion and signal delay. New fare policies may influence dwell times. Speed estimation based on the current schedule is insensitive to these changes.

2. Estimate speeds based on current transit running times

This method shares the same advantages and disadvantages as the previous method, except that it avoids the issue of the published schedule being inaccurate.

3. Estimate speed as a percentage of highway speed.

A model of transit speed as a percentage of highway speed is calibrated using observed transit and traffic data. The calculated percentage depends on a number of factors:

- Area type (central business district, other urban, rural, etc.)
- Facility type (freeway, arterial, etc.)
- Time of day (am peak, midday, etc.)
- Type of bus service (local, limited stop, etc.)

As an illustration, the Los Angeles County Metropolitan Transportation Authority developed values for well over 100 combinations of conditions. A few examples are shown below:

TABLE A.2 Transit Speed as a Percent of Highway Speed (from LACMTA)

Condition	**Transit speed as percent of highway speed**
Urban arterial, standard bus, AM peak	65%
Urban arterial, rapid bus, AM peak	78%
Urban arterial, standard bus, midday	45%
Urban arterial, rapid bus, midday	54%

Unlike the previous approaches, this method does capture the impacts of future changes in the highway system. It can also be used to estimate the run time of a new bus route, provided it is similar in operating characteristics to existing routes. However, it is data intensive, and won't capture all changes in conditions (i.e., going to a faster fare collection method). Appendix A presents an approach for estimating bus speed as a percentage of highway speed.

4. Calculation

Speeds are computed based on assumptions about cruising speed, acceleration, deceleration, dwell time, and congestion delay. TCRP Report 26 (*Operational Analysis of Bus Lanes on Arterials*, 1997) presents the results of some simulation analyses that were performed. TCRP Report 100 (*Transit Capacity and Quality of Service Manual*, 2003) provides information on dwell times and the impact of bus preferential treatments. TCRP Report 13 (*Rail Transit Capacity*, 1996) provides information on dwell times and operational issues for rail systems.

Advantages of this method are that it can be made sensitive to any factors of interest, and is usable for a completely new service. A disadvantage is that considerable effort may be required to develop and calibrate the model.

5. Simulation

A simulation is performed of the new route or the transit system improvement. This method arguably requires the most effort for model development and calibration.

Transfer Time

Transfer time includes both the time to walk from one vehicle to another and the wait time for that second vehicle. This wait time is typically set at 1/2 the headway since passengers have less control over their arrival time at a transfer point. However, for routes with large headways (>15 minutes), it may be assumed that passengers will attempt to time their arrival to the transfer point in order to minimize wait time.

Fare

Fare structures fall into one of three categories, zonal, flat fee, or a combination zonal and flat fee.

A.3.4 Transit Path Building

The final step in the building of a transit network is the determination of the transit paths and path attributes which will be used as inputs for the mode choice models.

When there is only one path available from an origin to destination, this step is trivial. However, it is not trivial when several paths are available. The general process is that first all the feasible paths from an origin zone to a destination zone are enumerated. Once the paths are enumerated for a particular origin-destination pair, some selection criteria (e.g., minimum impedance, optimal strategies, etc.) is used to chose the representative path, and it will be used in the mode choice analysis. This process is repeated for all zonal pairs until a complete set of transit paths are generated. Commonly used methods include shortest path, optimal strategies and pathfinder.

In most cases, transit path building does not consider transit capacity or effects of congestion in the passengers' path decision.

Shortest Path Method

This method is based on the assumption that all passengers will choose one path which minimizes the total generalized travel cost.

Optimal Strategies

This method can be viewed as a generalization of the concept of a single path, and it is based on the assumption that passengers only have information about the transit vehicle that arrives next at their current stop. Under this assumption, if the traveler can reach his destination via multiple paths, he may choose a path based on the first vehicle to actually arrive at his current stop. Furthermore, the traveler will exit the transit path at the stop that minimizes the travel time to his destination. Then at that point this process can be repeated until the traveler arrives at his destination. The so-called "optimal strategy" is the one that minimizes the total expected travel time from origin to destination for the traveler. This time includes all travel via access modes and transfer times.

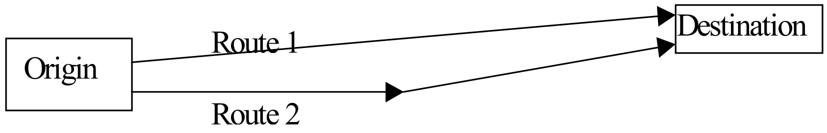
Pathfinder Method

This method combines links with similar service characteristics into what are called trunk links. The combining of similar links attempts to model overlapping service. Obviously for two transit links to be combined, they must have similar (not identical) characteristics such as in-vehicle transit time, fares, initial wait time, etc. Once the trunk links are created, then the same process is followed as in the shortest path method; however, there is a final step where passengers are allocated to the transit links that constitute the trunk link based on the frequencies of the component links.

Example

The following example illustrates the three path building techniques. Figure A.7 depicts a portion of a transit network, with two routes available.

FIGURE A.7 Simple Transit Network



Headways and travel times for the two routes are as follows:

TABLE A.3 Example Transit Routes

Route	Headway (minutes)	Vehicles/ Hour	Wait Time (minutes)	In-vehicle Travel Time (minutes)	Total Travel Time (minutes)
1	12	5	6	18	24
2	10	6	5	20	25

The shortest path method would choose route 1 all of the time, since it has the shortest overall travel time. This is why the shortest path method is often called an “All or Nothing” assignment method, as all the volume is assigned to one path.

Under optimal strategies, the passenger is assumed to choose the first vehicle to arrive at the origin. With an unknown random schedule, and random passenger arrivals, Route 1 would be chosen 45% of the time, and Route 2, 55% of the time.

The pathfinder method would combine the two routes to form a trunk link. The headways, transit times and other values would be averaged to determine impedances for the trunk link. 100% of the volume would be assigned to the trunk link. The trunk link would next be decomposed into its component links, and passengers assigned based on component link frequencies. Again 45% of passengers would be assigned to Route 1 and 55% to route 2.

Although the above example considers only service frequency and in-vehicle travel time, it is possible to include other factors (fare, comfort, reliability, arrival times, etc.) into the process, and passengers would be spread across the two routes according to these other factors.

A.4 Transit Demand

The previous section addressed the supply of transit service. That is, given that an individual was traveling via transit, what are the characteristics (travel time, etc.) of that individual's trip. This section addresses the third step of the traditional four step process, which is the modeling of what mode will be chosen for the trip. Methods for doing this fall into two groups: aggregate and disaggregate.

A.4.1 Aggregate Models

In the aggregate approach, the mode shares are directly modeled for a group of individuals, based on the observed mode shares and characteristics of that group.

Regression models seek to establish a statistical relationship between the mode shares and the socio-economic characteristics of the travelers and the attributes of the various modes. Cross-classification models seek to divide each TAZ into homogeneous groups based on either population characteristics (e.g. income, auto-ownership, etc.) or mode characteristics (e.g. travel times, costs, etc.). Once these groups are identified, the mode shares can be estimated either through surveying a sample of each group or through regression analysis.

A.4.2 Disaggregate Models

In disaggregate modeling, it is recognized that the observed mode shares are the result of many decisions by individuals. The mode choice decision is the result of the characteristics of both the available transportation modes and the decision-maker.

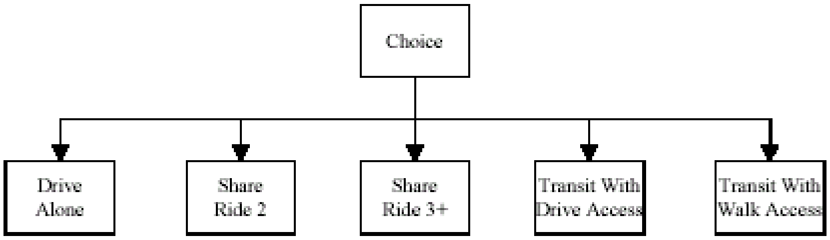
An individual's mode choice decision is viewed as a discrete choice from a set of alternatives. There are several flavors of disaggregate models. Accordingly, the following sections are organized as follows:

- Multinomial Logit Formulation. This is a basic logit formulation used to illustrate the fundamental concepts
- Incremental Logit Formulation. This variation is designed to deal with changes to an existing transportation system.
- Elasticities. In economics, elasticities are used to assess the impact of a change in inputs on demand. This section relates elasticities to the logit formulation.
- Independence of Irrelevant Alternatives (IIA). IIA is a property of logit models that may lead to incorrect results with some formulations.
- Nested Logit Formulation. This formulation is designed to address some of the problems created by the IIA property.

Multinomial Logit Formulation

The Multinomial Logit (MNL) model outputs the probability that an individual will utilize a specified mode of transportation. Figure A.8 shows an example of a multinomial logit hierarchy.

FIGURE A.8 Multinomial Logit Hierarchy



This probability is based on the utility of a specific mode for a specific passenger, which is $U_i + \varepsilon$. U_i represents the deterministic components of the utility, while ε is an error term, representing the random, non-measured components. Key assumptions about the error term include the following:

- It is Gumbel[1] distributed

- The error components are identically and independently distributed across alternatives, individuals and observations.

The probability of choosing mode i is given as

(EQ 2)

$$P_i = \frac{e^{U_i}}{\sum e^{U_k}}$$

The utility U_i can be interpreted to signify the amount of satisfaction a traveler or group of travelers receives from using a particular mode. It is modeled as the sum of a set of explanatory variables. There are three types of explanatory variables which determine the probability that a person will choose a particular mode.

- Traveler variables (e.g., income, gender, age, household size, auto ownership)
- Mode variables (e.g., in-vehicle travel time, out of vehicle travel time, cost, comfort)
- Trip variables (e.g., work trips, non-work trips)

These three types of variables are used to determine the utility for each mode, which, in a simple application, may take the following form:

U = a + b x IVTT + c x OVTT + d x COST + e x SEC

where

U = utility of using transit

a = mode-specific constant term

b = coefficient for IVTT variable(s)

IVTT = in-vehicle travel time

---

1. The Gumbel distribution closely approximates the normal distribution, but leads to much more tractable computations in mode choice modeling. The standard cumulative distribution function is F(x) = exp(-exp(-x)).

c = coefficient for OVTT variable(s).

OVTT = out-of-vehicle travel time

d = coefficient for direct out-of-pocket cost.

COST = fare

e = vector of coefficients of socio-economic factors

SEC = vector of socio-economic factors (household include, automobile availability, etc.)

NCHRP Report 365 suggests some typical values for the coefficients b, c and d (Barton-Aschman, 1998):

TABLE A.4 Typical Mode Choice Model Coefficients

	Value	**Comment**
b	-0.025	IVTT coefficient, where IVTT is in minutes. Typical range is –0.017 – -0.028, and the ratio of the IVTT coefficient and the cost coefficient implies value of time of about 25% of median hourly income.
c	-0.05	OVTT coefficient, where OVTT is in minutes. Typical range is –0.030 - -0.077. It is about twice as large in magnitude as the IVTT coefficient.
d	-0.005	Cost coefficient, where cost is in cents. Value depends on median income.

Often, the OVTT component is split into separate variables and coefficients for walk time, initial wait time, and transfer time(s). In the next few sections, we will explore the relationship between each of these terms and the service attributes mentioned earlier.

Mode-specific Constant Term (a)

This is an adjustment factor that depends on the attributes of the service. Attributes of the service that may affect the mode-specific constant include convenience, safety, security, and possibly, perceived reliability.

Convenience has a significant impact on demand (Charles River Associates, TCRP Report 27, 1997). Although several “convenience” factors may be at least partially related to the coefficients of in-vehicle and out-of-vehicle travel time (for example, the comfort of the vehicle may be related to the coefficient for IVTT), others are not related to these travel times. Such factors include the passenger’s ability to find out about transit services and convenience of fare payment. The aspects of convenience that are not related to travel time are reflected in the mode-specific constant.

Safety and security are factors that may or may not have an impact on demand. In services that are already perceived to be safe, safety and security improvements (such as on-board cameras and silent alarms) will probably have little impact on demand. In services that are perceived to be dangerous, safety and security improvements may have substantial impact if they are able to change this perception of danger.

Perceived reliability will be discussed later, as it has a significant role in other parts of the utility equation, in particular, OVTT.

Improper specification of travel models can result in the estimation of constants that compensate for upstream errors. It is therefore difficult if not impossible to understand how much of the alternative specific constant actually acts as a proxy for comfort, convenience, reliability, and other factors.

In-vehicle Travel Time (b x IVTT)

The coefficient (b) represents the "cost" of in-vehicle travel time. It is influenced by attributes of the service. A comfortable, safe, secure service with enroute information available may result in a coefficient for in-vehicle travel time that is less unfavorable (i.e. closer to zero).

Current practice is to use the same IVTT coefficient for all modes. There is some debate about this in the modeling field now, because in cases where models have been estimated with different IVTT coefficients for transit and auto, in-vehicle time for auto was found to be more onerous.

Given a transit path, one of the methods discussed in Section A.3.3, "Transit Attributes" can be used to estimate total in-vehicle time.

Out-of-vehicle Travel Time (c x OVTT)

Because the coefficient for OVTT is often twice as large in magnitude as the coefficient for IVTT, this is an important term in the utility equation. OVTT includes several components:

- Access time (walk) to reach the initial transit stop from the origin[2]
- Wait for the initial transit vehicle
- If the trip involves one or more transfers, walking time for the transfer and the wait for the subsequent transit vehicle
- Access time (walk / drive) from the final transit stop to the destination

A more reliable service, by reducing passenger anxiety, might reduce the value of the coefficient c. Passengers who place a high importance on arriving no later than a particular time may also find a more reliable service more attractive.

To quantify these impacts, one needs, first, to assess the reliability of a given transit service (via, possibly a distribution of wait times and total travel times). Second, one needs to assess desirability of various degrees of reliability from a passenger's standpoint. For example, would a passenger prefer a travel time that is consistently 30 minutes, versus a travel time that is 20 minutes 90% of the time, but 60 minutes 10% of the time? Since the expected travel time in the latter case is 24 minutes ($24 = 20 \cdot 0.9 + 60 \cdot 0.1$), the risk-neutral passenger would prefer the latter. However, a risk-averse passenger might prefer the constant 30-minute travel time.

<u>Cost (d x COST)</u>

Direct out-of-pocket cost is easily measured, although the widespread use of monthly transit passes may complicate the measurement, by reducing the marginal cost for some users to zero.

An Example

Consider a passenger's usage of a bus service with the following characteristics:

- 5 minutes access time (a)
- 10 minute headway, hence an assumed 5 minute wait time (w)

---

[2] Auto access time is often considered to be ***in***-vehicle time

- 20 minute in-vehicle time (i)
- \$1.00 fare. (f)

We have a model with the following coefficients

- -0.05 for access time
- -0.05 for wait time up to 7 minutes
- -0.025 for wait time in excess of 7 minutes
- -0.025 for in-vehicle travel time
- -0.005 for the fare.
- 0.114 alternative specific constant for this mode. (The alternative specific constant is calibrated based on the observed mode share, and is designed to ensure that the modelled mode share matches the observed.)

The utility is computed as

U = -0.05 a - 0.05 w - 0.025 i - 0.005 f + 0.114

Plugging in the above numbers for access, wait, in-vehicle times and fare, the total utility is -1.386.

The mode share will depend upon the utilities of the other (non-chosen) modes. If we assume one other mode (auto) with a utility of zero, the probability of choosing the bus is computed as

$$\frac{\exp(-1.386)}{(\exp(-1.386) + \exp(0))} = 0.2$$

Incremental Logit Formulation

The Incremental Logit model is a variation of the MNL model because it does not require a complete set of explanatory variables. The incremental model seeks to evaluate the change in mode share based on changes in the explanatory variables. Therefore, only the explanatory variables which changed from the base scenario and the previous mode shares need to be input into the modal. This type of model is well suited to evaluating potential improvements in a network, and it is formulated as follows:

$$P_i' = \frac{P_i \cdot e^{\Delta U_i}}{\sum P_k \cdot e^{\Delta U_k}} \qquad \text{(EQ 3)}$$

Where:

- P_i = The existing probability of using mode i
- P_i' = The new probability of using mode i based on the potential improvement(s)
- $\Delta U = U_i' - U_i$
- U_i' = The new utility for mode i based on the potential improvement(s)
- U_i = The existing utility for mode i
- k = The set of all available modes

Elasticities

A frequently used measure of the ridership response to a change in system attribute is the elasticity. The elasticity is defined as

$$\frac{(\Delta P)/P}{(\Delta X)/X} \qquad \text{(EQ 4)}$$

where

P = Probability of using the mode

X = the value of an attribute

The logit model offers a convenient formula for computing point elasticities. The elasticity is simply the product of three quantities: X and P were used in equation 4, and c is the coefficient of the attribute:

(EQ 5)

$$cX(1-P)$$

If the probability of choosing the mode is 20%, the elasticities in our above example are computed as follows.

Attribute	**Coefficient**	**Value**	**Elasticity**
Walk time	-0.05	5 minutes	-0.2
Wait Time	-0.05	5 minutes	-0.2
In-vehicle Time	-0.025	20 minutes	-0.4
Fare	-.005	100 cents	-0.4

Elasticities may also be computed as arc elasticities, based on the before and after probabilities (P) and the before and after values of the attribute in question (X). The arc elasticity is computed as

(EQ 6)

$$\frac{(P_2-P_1)/((P_1+P_2))/2)}{(X_2-X_1)/((X_1+X_2))/2)}$$

An Example (continued)

To illustrate the impact of changes to a transit service and the relationship between model coefficient and elasticities, a number of changes are made to the transit service in the above example. Recall that this service had the following characteristics:

- 5 minutes access time (a)

- 10 minute headway, hence a 5 minute wait time (w)
- 20 minute in-vehicle time (i)
- \$1.00 fare. (f)
- 20% observed mode share

<u>Case 1: Raise the headway to 20 minutes.</u>

With this change, the wait time increases from 5 to 10 minutes. The total utility of waiting changes as follows:

ΔU = -0.05 x 7 minutes + -0.025 x 3 minutes – (-0.05 x 5 minutes) = -0.175.

The calculated mode share decreases from 20% to 17.35%, a change of 13%.

The point elasticity (from the above table) is –0.2 while the calculated arc elasticity is also –0.2

<u>Case 2: Raise the in-vehicle time from 20 to 25 minutes.</u>

With this change, the total utility of using transit changes as follows:

-0.025 x 5 minutes = -0.125

The calculated mode share decreases from 20 to 18.1%, a change of 10%.

The point elasticity is –0.4, while the calculated arc elasticity is -0.43.

<u>Case 3: Reduce the in-vehicle time from 20 to 15 minutes.</u>

With this change, the total utility of using transit changes as follows:

-0.025 x -5 minutes = 0.125

The calculated mode share increases from 20 to 22.1%, a change of 10%.

The point elasticity is –0.4, while the calculated arc elasticity is –0.36.

Case 4: Raise the fare by 20 cents, from \$1.00 to \$1.20

The total utility of using transit changes as follows:

-0.005 x 20 = -0.1

The calculated mode share decreases from 20% to 18.45%, a change of 8%.

The point elasticity is –0.4 while the calculated arc elasticity is –0.43.

Independence of Irrelevant Alternatives

The Independence of Irrelevant Alternatives (IIA) property states that the choice between two alternatives does not depend on the existence of other alternatives in the choice set. It is a result of the assumption made that the error terms in the utility function are independently distributed. Sometimes, however, this assumption is violated. Consider the following example:

Case 5: Raise the headway to 20 minutes (as in Case 1), but also add a new service with a headway of 20 minutes

Recall that the Case 1 transit mode share was 17.35%, leaving an auto mode share of 82.65%. The ratio of transit to auto is 17.35/82.65, or 0.21. Under IIA, this 0.21 ratio should remain constant if the new service is added. However, the new transit service is identical to the Case 1 transit service, and should have the same mode share as the Case 1 transit service. Let

- A: Mode share of the transit service in Case 1
- B: Mode share of the new transit service
- C: Auto mode share.

The relationships among A, B, and C are as follows:

- A + B + C = 1
- A = B (because the transit service of Case 1 and the new transit service have the same characteristics)
- A / C = 0.21 (from Case 1)

Solving these equations yields

A = B = 0.148, and C = 0.704. The TOTAL transit mode share is 29.6%.

However, the combined transit services, each with a headway of 20 minutes, can be considered to be the equivalent of a single transit service with a headway of 10 minutes. This was our base case (page 197), that had a modeled mode share of 20%, not the 29.6% calculated here.

What is happening, of course, is that when the new transit service is added, it will draw primarily from users of the existing transit service. Those passengers who are inclined to use the existing transit service will be the same passengers as those inclined to use the new transit service. Therefore, the total transit mode share will not increase nearly as much as was suggested in Case 5.

Nested Logit

The nested logit model was developed to deal with the case where IIA is violated. This normally occurs when some of the alternative modes are more similar to each other than to other modes. These relationships violate a key assumption of the MNL model that utilities of alternatives are independent, known as the Independence of Irrelevant Alternatives (IIA). This may occur in the cases where more than one transit alternative is available, access modes are considered, or auto occupancy is considered. There are statistical tests which can be used to determine the violation of the IIA assumption in a particular model. This problem can be reduced by using a hierarchy of distinct sets of alternatives. With this nested structure, the mode shares of the higher levels (Auto & Transit) depend on the mode shares of the lower level alternatives (Walk, Drive, Single Occupancy, Multiple Occupancy). So the first step in solving this type of problem is to solve for the mode shares in the lower tiers.

Using Figure A.9 as an example, the calculations for the conditional mode shares Transit with Walk Access (P_w) and Transit with Drive Access (P_d) are shown in equations 7 and 8.

$$P_w = \frac{e^{U_w}}{e^{U_w} + e^{U_d}} \tag{EQ 7}$$

$$P_d = \frac{e^{U_d}}{e^{U_w} + e^{U_d}} = 1 - P_w \tag{EQ 8}$$

The same equations can be applied to determine the mode shares for Auto Single Occupancy (P_s) and Auto Multiple Occupancy (P_m). The next step in the process is to calculate the composite utilities of the lower tier modes.

$$CU_{transit} = \ln(e^{U_w} + e^{U_d}) \tag{EQ 9}$$

$$CU_{auto} = \ln(e^{U_s} + e^{U_m}) \tag{EQ 10}$$

The shares of the higher level alternatives are calculated as follows:

$$P_{auto} = \frac{e^{\beta_{auto} \cdot CU_{auto} + C_{auto}}}{e^{\beta_{auto} \cdot CU_{auto} + C_{auto}} + e^{\beta_{transit} \cdot CU_{transit} + C_{transit}}} \tag{EQ 11}$$

$$P_{transit} = 1 - P_{auto} \tag{EQ 12}$$

Where:

- β_i the nesting coefficient for mode i ($0.0 \le \beta_i \le 1.0$)
- C_i the mode specific coefficient for mode i

The value of β_i is indicative of the independence of the alternatives. A value of one reduces this problem to a standard multinomial logit model, indicated that the IIA assumption was valid. A value of 0 indicates that the lower level alternatives are completely independent from the higher level alternatives. These values are typically estimated from the analysis of the study area's characteristics, the passengers' characteristics, and survey data collected pertaining to passengers' behavior. A second way to calibrate this constant is to use a constant calibrated in another similar urban area and adjust it as necessary for the model to predict values within a certain target range.

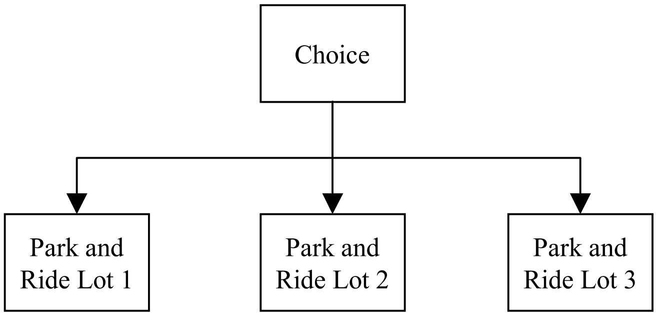
The method for calibrating the mode specific constant C_i is through an iterative process, where C(i+1) = C(i) - ln(Pestimated/Pobserved) (Eq. 13).

This process stops when a mode's estimated share is equal to its observed share (e.g. $C_{i+1} = C_i$).

Further Applications of Logit and Nested Logit Models

There is a further application of the logit model dealing with the assignment of the transit trips with an access mode of auto to a particular park and ride lot. In some areas passengers may have the choice of several park and ride lots, with different distances, transit times, and/or fares. This problem can be formulated into the logit structure as shown in Figure A.9.

FIGURE A.9 **Nested Logit Model for Park and Ride**



Once the number of trips through each park and ride lot has been determined from the logit model, then a total cost for the route can be computed by adding in the auto cost ($/mi) to the transit cost. Also a weighted average for the cost from some origin zone to a particular destination zone can also be computed and used in the transit network characteristics. It should also be noted that this problem can be solved with a nested logit structure; however, there are number of added complications that need to be taken into account so that illogical trips are not generated (e.g. returning to the traveler's origin park and ride lot).

A.5 Time of Day Analysis

Although this is not a step in the traditional four step process, for some MPOs it does have implications for transit analysis mainly in the modeling of park and ride access. This step assigns trips to the period of day in which they occur (e.g. Peak A.M., Peak P.M., Night, Off-Peak, etc.), and it also decomposed park and ride trips into their component transit and auto trips. The purpose of decomposing these trips by mode and time of day is so that each can be assigned separately in the transit assignment step. One shortcoming of this step in the process is that it cannot estimate passenger shift from one time period to another time period due to the effects of congestion.

A.6 Transit Assignment

Transit assignment is the final step in the traditional process whereby individual trips are assigned to particular routes in the transit network. There will be a different assignment by trip purpose and by time of day. This step is analogous to traffic assignment where automobile trips are assigned to particular routes in the highway network. There are two main classification of methods that can be used to assign individual trips to routes, equilibrium and non-equilibrium. Equilibrium methods take into account the capacity of the transit service and the effect of crowding and dwelling times at stations on ridership. Non-equilibrium methods, such as shortest path, do not take these factors into account.

A.6.1 Equilibrium Methods (Capacity Constrained)

Equilibrium methods are based on the assumption that passengers may choose to utilize an alternate route in a heavily congested transit network. Heavily congested links in the transit network may reduce the comfort level of the passengers in the transit vehicles and may also prevent passengers from boarding a transit vehicle if the vehicle reaches its maximum occupancy level. Furthermore, due to the high numbers of boardings and alightings, dwell times will increase. This increases the in-vehicle travel time, and may reduce service reliability. All of these will encourage travelers to seek alternate paths to their destination. Equilibrium methods model this phenomenon by introducing factors into the cost equation which increase the link cost as the passenger level increases thereby making the link less attractive to subsequent travelers. Several commercial modeling packages now offer ways to model capacity constraints. One such method involves iteratively weighting the headway in order to simulate the effects of congestion in the transit network.

A.6.2 Non-Equilibrium Methods (Non-Capacity Constrained)

Historically, many different non-equilibrium methods for creating transit assignments have been proposed, with the main differences being the assumptions made about how a traveler chooses a particular path. They all share the assumption that transit capacity is not an issue; therefore, a traveler's path choice does not depend on the choice made by other travelers. Examples on non-equilibrium methods include shortest path, optimal strategies and pathfinder. They were discussed earlier.

A.6.3 Conclusion

The goal of this evaluation was to identify methods currently being used to model transit modes in the transportation planning process. In conclusion it has become increasingly obvious that in order to accurately represent transit modes, planning models need to accurately represent:

- the methods by which a passenger arrives at the transit route (access modes and network representation)

- the modeling of transit supply attributes, such as wait time

- the assignment of individual trips to specific routes including congestion effects.

APPENDIX B

Bus Speed Calculations

ITS improvements may have a direct impact on transit speeds, and may also affect the performance of a road that is shared by both automobiles and buses. As discussed in Chapter 2, currently used methods of measuring transit speeds may not properly capture the impacts of ITS improvements. For example, using current schedules or running times does not capture the impacts of improvements at all. Assuming that transit speed is a fixed percentage of highway speed does not consider that this percentage will most likely change as highway speeds change. (The relative speed disadvantage of a bus becomes less as highway speeds are reduced, particularly in situations where stops are frequent.)

In this appendix, we expand on the discussion of bus speed calculations given in Chapter 2. We present a closed form approximation of bus speed as a percentage of highway speed. This approximation is based on highway speed, stop spacing, dwell time, and bus acceleration characteristics. We then compare this approximation to some of the results presented in TCRP Report 26 (*Operational Analysis of Bus Lanes on Arterials,* 1997).

B.1 Closed Form Approximation

A bus traveling from one stop to the next stop is modeled in four steps:

- Dwell time at the stop. This includes passenger loading / unloading, door opening/closing time, and any time lost waiting to reenter traffic.
- Acceleration to cruise speed.
- Cruise. The cruise speed is assumed to be equal to the auto speed, which is a function of both free flow speed and the volume/capacity ratio. It is assumed that the stop spacing is wide enough and/or the auto speed is low enough so the bus is actually able to reach cruise speed.
- Deceleration to the next stop.

We compare the ratio of the time it takes an auto to travel the distance between the two stops versus the time is takes a bus to complete these four steps. Variables are as follows:

Va = auto speed (ft / sec)

Vb = average bus speed (ft / sec)

Td = dwell time (sec) Includes passenger boarding/alighting, door opening/closing and time spent waiting to re-enter traffic

Ta = acceleration and deceleration time (sec.). TCRP Report 100 (*Transit Capacity and Quality of Service Manual*, 2003) states that for grade separated busways, a rate of 4 ft/ sec^2 for both acceleration and deceleration may be used in the absence of local data. This rate is also used in TCRP Report 23 (section B3.1). With this rate, the time required for acceleration or deceleration is simply Ta= Va / (4 ft/ sec^2)

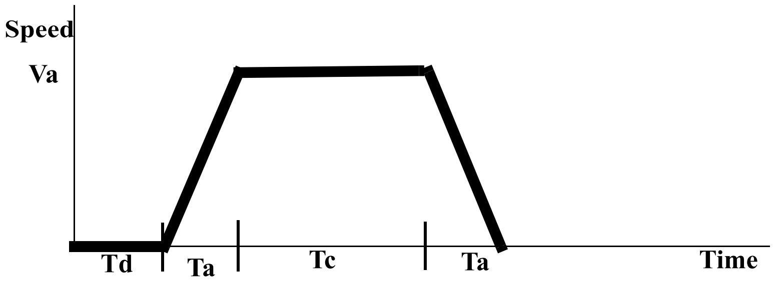
Tc = cruise time (sec).

S = stop spacing (feet)

Figure B.1 depicts the speed profile for a bus traveling from one stop to the next stop. The time required between arrival at the first stop and arrival at the second stop is Td + Tc + 2Ta. Therefore, the average bus speed is

$$Vb = S / (Td + Tc + 2Ta) \quad \textbf{(EQ 1)}$$

FIGURE B.1. Bus Speed Profile



The distance traveled by the bus is equal to the area under the trapezoid. Therefore, the stop spacing is also equal to the area under the trapezoid (Equation 2). The value of Tc can be determined as a function of the other variables (Equation 3). As stated earlier, Ta is assumed equal to Va / (4 ft/ sec^2).

$$S = Va(Ta + Tc) \quad \textbf{(EQ 2)}$$

$$Tc = S/Va - Va/4 \quad \textbf{(EQ 3)}$$

By manipulating equations 1 and 3, bus speed is

$$Vb = S / (Td + S / Va + Va / 4) \quad \textbf{(EQ 4)}$$

The ratio of bus to auto speed is

$$Vb/Va = S / (VaTd + S + Va^2 / 4) \quad \textbf{(EQ 5)}$$

Note that Equations 4 and 5 are only valid if Tc (Equation 3) is greater than or equal to zero. Table B.1 presents a comparison of speeds calculated from Equation 4 with those given in TCRP Report 26. In this table, the dwell time (Td) for equation 4 is calculated as the sum of the time per stop given in the leftmost column plus 7 seconds to re-enter traffic.

.

TABLE B.1. Calculated Bus Speeds: TCRP-26 versus Equation 4

Time/ Stop	Stops/ mi	From Table A-6 TCRP 26				Equation 4 for various auto speeds (mph)					
(sec.)		CBD	City	Suburb	No Delay	10	15	20	25	30	35
10	2	11	18	19	25	9	13	16	18	21	22
10	4	10	14	15	18	8	11	13	15	16	16
10	6	8	12	12	14	7	10	11	12	13	13
10	8	7	10	10	11	7	9	10	10	11	11
10	10	6	8	8	9	6	8	9	9	9	n/a[a]
20	2	11	17	18	22	9	12	15	17	18	20
20	4	9	12	13	15	8	10	11	13	13	14
20	6	7	10	10	11	7	8	9	10	10	11
20	8	6	8	8	9	6	7	8	8	9	9
20	10	5	6	6	7	5	6	7	7	7	n/a
30	2	10	15	16	20	8	11	13	15	17	18
30	4	8	11	11	13	7	9	10	11	12	13
30	6	7	8	9	5	6	7	8	9	9	9
30	8	6	7	7	8	5	6	7	7	7	7
30	10	5	5	6	6	5	5	6	6	6	n/a

---

a. In the cells marked n/a, the bus does not ever reach cruising speed; therefore Equation 4 is not valid. However, the average bus speed is approximately equal to the speed found in the cell immediately to the left (auto speed 30 mph) of the cell that is marked n/a.

In planning models, an auto travel time is typically computed for each link as a function of the free flow travel time, volume and capacity. Equation 6 presents a typical formulation:

(EQ 6)

$$T_{actual} = T_{FreeFlow}\left(1 + a\left(\frac{v}{c}\right)^{b}\right)$$

In equation 6, v/c is the volume capacity ratio, and a and b are parameters. The parameter a is typically between 0 and 1, while b might be between 2 and 8. For example, NCHRP Report 365 suggests that appropriate values in small urban areas for a and b are 0.15 and 5.5. The actual travel time is often capped, so that it does not become ridiculously large when v/c is much greater than 1.

Table B.2 presents bus speed as a fraction of auto speed. Note that as auto speeds become lower, the ratio of bus to auto speed becomes significantly higher.

TABLE B.2. Bus Speed as a Fraction of Auto Speed (Equation 5)

Time/ stop (sec.)	Stops/ mi	Auto Speed (mph) 10	15	20	25	30	35
10	2	.90	.84	.79	.73	.68	.63
10	4	.81	.73	.65	.58	.52	.46
10	6	.74	.64	.55	.48	.42	.36
10	8	.69	.57	.48	.41	.35	.30
10	10	.64	.52	.43	.35	.30	n/a
20	2	.85	.79	.72	.67	.61	.56
20	4	.75	.65	.57	.50	.44	.39
20	6	.66	.55	.47	.40	.34	.30
20	8	.59	.48	.40	.33	.28	.24
20	10	.54	.42	.34	.28	.24	n/a
30	2	.82	.74	.67	.61	.56	.51
30	4	.69	.59	.50	.44	.38	.34
30	6	.60	.48	.40	.34	.29	.26
30	8	.53	.41	.34	.28	.24	.21
30	10	.47	.36	.29	.24	.20	n/a

B.2 Discussion

The formulation presented above has three attractive features:

- Its results appear to be reasonable, and change in the appropriate way as dwell times, stop spacings and auto speeds change
- It is not overly compuationally intensive

- It is sensitive to changes in dwell times, stop spacings and auto speeds that might result from an ITS or BRT implementation. It does not include the impact of transit signal priority. Transit signal priority was addressed separately in Chapter 5. It also does not include the impact of dedicated bus lanes, which were addressed in TCRP Report 26.

A logical next step would be to calibrate the model, by comparing actual bus and auto speeds in mixed flow traffic, under varying congestion conditions.