# *Executive Summary*

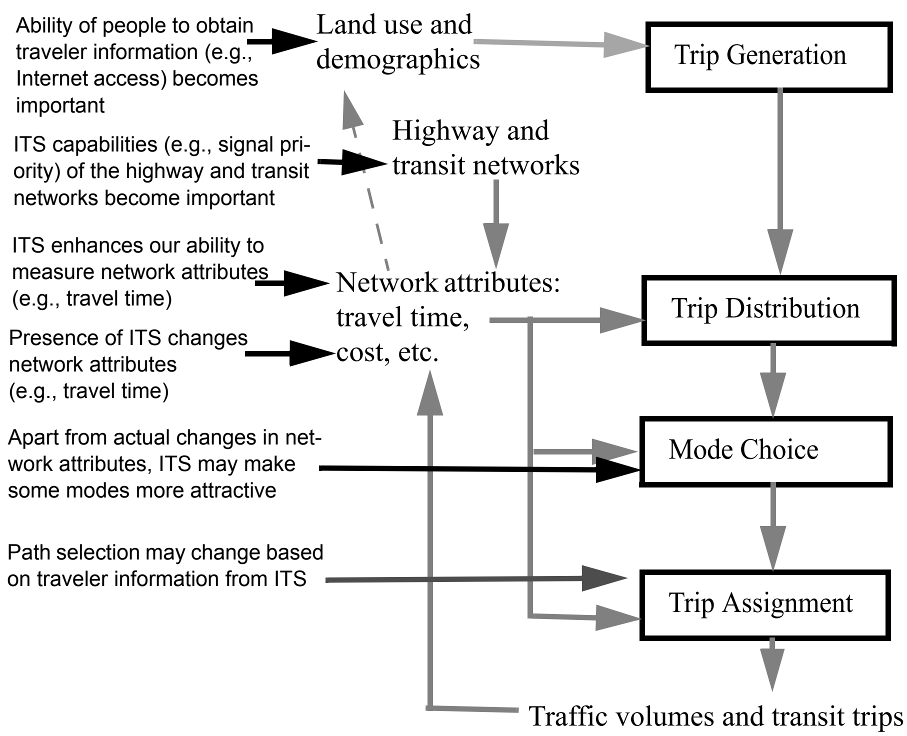
The use of Intelligent Transportation Systems (ITS) technology in new public transit investments, such as Bus Rapid Transit, has two major impacts on the planning process. First, the technology can provide new, better and more abundant data that may be used for planning. Second, the technology may improve 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<br>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<br>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.

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.