A Transit Signal Priority Impact Assessment Methodology—Greater Reliance on Simulation

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Introduction

Across the country, transit and road agencies are working closer together than ever before to address transportation problems facing their communities. This increasingly cooperative environment is leading these agencies to embrace operational strategies to increase people moving capacity that have not been well received in the past. Although these strategies are being embraced, skepticism still remains regarding their effectiveness. In order to address this skepticism, evaluation methodologies that satisfy the concerns of a diverse set of stakeholders are needed. The methodologies also have to be economical, which can be achieved through a greater reliance on simulation models.

The metropolitan area in Seattle, Washington, is pursuing an operational strategy that typically generates some contention between transit and road agencies. This strategy is transit signal priority (TSP). King County's Department of Transportation is the lead agency for TSP implementation through the Puget Sound's Regional Automatic Vehicle Identification Demonstration Project as part of the Metro Transit Division Speed and Reliability Program. Program managers realized from the start that a methodology to assess TSP impacts would be needed for two primary reasons:

- Skepticism exists regarding the effectiveness of TSP, especially its impact on traffic operations along signalized arterial streets. Therefore, the concerns raised by the agencies operating the traffic signals would need to be addressed.

- Decision-makers will need information about benefits to justify the investment in TSP to their constituents.

The TSP impact assessment methodology resulting from stakeholder participation consists of two primary components: (1) field studies and (2) simulation. Field studies provide a real world assessment of TSP impacts and a means to validate the simulation model. Simulation, in turn, permits the evaluation of various TSP operating strategies without the considerable expense of extensive before and after field data collection.

This paper documents the process used in Seattle, Washington by the King County DOT to develop a TSP impact assessment methodology. Where as the experience gained through developing the TSP impact assessment methodology is in some ways unique to Seattle, Washington, these experiences can provide insight to other transportation professionals developing methodologies to assess similar operational strategies.

PAPER ORGANIZATION

The following discussion is organized into five sections.

1. Overview of the Puget Sound's Regional Automatic Vehicle Identification Demonstration Project and Stakeholder Involvement

2. Impact Assessment Methodology

3. Conclusions and Findings

4. Recommendations

5. References

PUGET SOUND'S REGIONAL AUTOMATIC VEHICLE IDENTIFICATION DEMONSTRATION PROJECT OVERVIEW

The Puget Sound Automatic Vehicle Identification (AVI) Demonstration Project evaluates one AVI technology and several TSP technologies aimed at reducing congestion, delay, transit travel time, and harmful emissions; increasing person throughput and transit schedule reliability; and encouraging multimodal shift into high-occupancy vehicular travel. The challenging nature of AVI and TSP technologies require not only interjurisdictional cooperation and agreement, but also a private-public partnership to develop the advanced TSP systems. The following elements comprise the AVI/TSP system: on-vehicle equipment, on-street equipment, AVI interface unit, controller firmware modifications, base computer and TSP strategies. System installation occurs during late 1998 and evaluation in 1999. Project development costs are federally funded through the Surface Transportation Program (STP) and the Congestion Management and Air Quality Improvement Program (CMAQ) of the Intermodal Surface Transportation Efficiency Act (ISTEA). A schematic of the AVI system being employed by King County Metro is shown in Figure I.

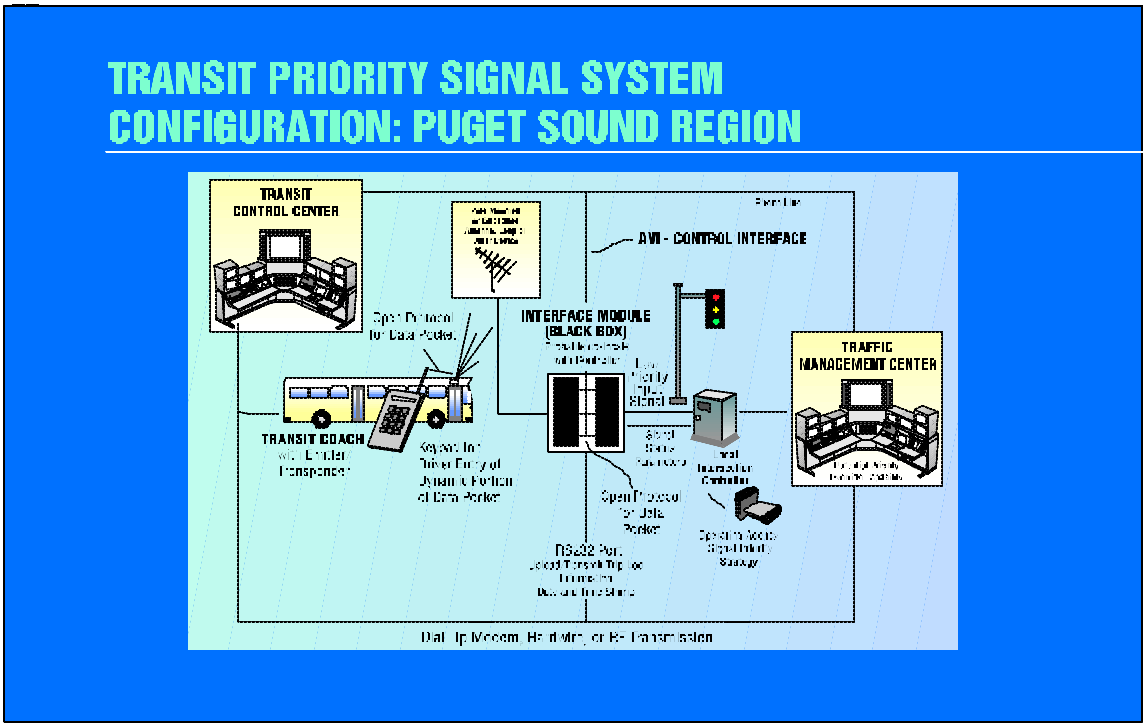

Figure 1. Transit Priority Signal System Configuration

The purpose of the demonstration project is to develop TSP control strategies on two major arterial streets divided into four study segments and evaluate their impacts. These arterial streets operate independently and are named Rainier Avenue South (one signal operating jurisdiction, 9 signals, 2.1 miles in length) and Aurora Avenue North (three signal operating jurisdictions: 22 signals; 6.2 miles in length). Specific objectives include: (1) determine the impact of a TSP system that uses AVI technology and (2) evaluate the effectiveness of different TSP operating strategies. The evaluation of the TSP demonstration will largely be based upon comparisons of operations between four study segments in the demonstration. Major stakeholders hope to be able to learn from this experience determining how to optimize TSP intersection design and control strategies for future applications.

Stakeholder Involvement

Stakeholders (i.e., agencies "affected" by the TSP system) were the driving force behind the development of the impact assessment methodology for the King County Demonstration Project. Stakeholders included transportation operating agencies in King County directly involved with the project: Washington State Department of Transportation, King County Transit and Roads Divisions, City of Seattle, and City of Shoreline and the City of Bellevue. In addition, other jurisdictions and transit properties were directly involved in selecting the regional AVI technology and have a keen interest in the outcome of the impact study. Included are the City of Everett and Everett Transit, Community Transit, Snohomish County, the City of Edmonds, and the City of Lynnwood. These agencies participated on a proposal selection board as key forces in the selection of a single AVI technology that would be seamless across the jurisdictional boundaries served by several transit agencies. In addition, these agencies continue to provide regional oversight during implementation.

For any multijurisdictional project, stakeholders need to be identified early and involved throughout the project. Stakeholders in this project were involved through meetings to discuss progress on the methodology's development and reviewing drafts of the methodology. This approach provided numerous opportunities for stakeholders to express their concerns and ensure their concerns were addressed by the methodology. Consequently, this approach also fosters ownership of the methodology (as well as the project) among the stakeholders. Stakeholder concerns were in general related to four areas: (1) traffic impacts, (2) transit impacts, (3) air quality, and (4) safety. In the end, the methodology was designed around these/their concerns.

Control Strategies

Traffic congestion and delay in an arterial environment is largely a function of signalized intersections through the constraints they place on roadway vehicle capacity. A TSP system serves to reduce delay imposed on transit vehicles by recognizing buses with AVI tags and altering traffic signal timing to favor their passage. Each traffic signal operating agency (City of Seattle, City of Shoreline and Washington State Department of Transportation) is developing specific TSP strategies consistent with their existing signal operating policies. All three jurisdictions propose to use minor variations of the green extension/red truncation strategy. Green extension provides added green time if a TSP service call is requested from an approach currently being serviced. Red truncation, sometimes called early return to green, applies when a TSP service call is requested during that approach's red phase. Once requested, the other approaches receive reduced green splits to accelerate the return to the approach where the requested TSP service call is active. Selected signal vendors are working to modify controller firmware to incorporate TSP strategies. The objectives of these strategies, as requested by stakeholders, included not skipping signal phases, maintaining pedestrian and vehicle clearances, and keeping in coordination.

The primary objective of a TSP system and operating strategy is to produce a travel time benefit along the transit arterial corridor by decreasing overall person delay. As a result, the philosophy behind developing TSP control strategies is to operate traffic signals to minimize total *person* delay, an evolutionary step from current signal control strategies, which serve to minimize total *vehicle* delay. Success in achieving the primary objective of TSP usually requires that any increase in person delay on cross streets has to be more than offset by the reduction in total person delay on the arterial. A TSP system may also have a number of secondary objectives, including reducing bus delay/stops, improving transit schedule reliability, improving passenger comfort, attracting more ridership, maintaining or improving total vehicle emissions, lowering overall accident rates, and reducing total vehicle delay (1). To assess TSP impacts, King County DOT worked with the stakeholders and selected a two step evaluation approach including: 1) field studies and 2) simulation.

Why use field studies and simulation to evaluate TSP when both can produce the same measures of effectiveness (MOEs)? When an unfamiliar operating strategy is being implemented, especially one that has garnered a considerable amount of skepticism in the past, field studies documenting the strategy's effectiveness are needed to satisfy stakeholder concerns. Field studies also provide a means to validate simulation models. Simulation holds the promise of reducing the need for extensive and costly field studies, but requires time for stakeholders to become familiar with the model and develop confidence in its ability to replicate field conditions. Realizing the initial need for extensive field studies and the long-term need for a more cost-effective approach to address stakeholder concerns, King County DOT will initially use field studies and simulation. In the future, however, King County DOT will rely more heavily on simulation to evaluate the impacts of future TSP implementations.

IMPACT ASSESSMENT METHODOLOGY DEVELOPMENT

This portion of the paper is organized into the two components involved in designing the TSP impact assessment methodology: (A) field data collection, and (B) simulation. Key to the methodology is identifying appropriate measures of effectiveness (MOEs) to evaluate TSP impacts. The field data collection component is presented which focuses on appropriate MOEs and field data collection techniques, statistics for before and after studies, study locations, and data collection and reduction responsibilities. The last component, simulation, discusses the benefits of simulation, model requirements, and validation.

Field Data Collection

This section starts with a brief overview of the four pilot study segments and the process used to select study intersections. Next, MOEs and field data collection techniques are discussed. The final section presents the statistical tests proposed to assess TSP impacts.

Study Segments and Intersections

Two arterial street transit corridors were selected for study in the King County Demonstration Project: Aurora Avenue and Rainier Avenue. The Aurora Avenue corridor is divided into three segments for purposes of implementation. Together, four segments are studied. Table 1 summarizes the characteristics of the four segments ordered from north to south.

Table 1. Study Segment Descriptions

Study Segments	Signalized Intersections	Segment Length (miles)
Aurora Ave. (North): 205th St. - 155th St.	7	2.5
Aurora Ave. (Middle): 145th St. - 107th St.	7	1.9
Aurora Ave. (South): 105th St. - Winona Ave.	8	1.8
Rainier Ave.: S Alaska St. - 23rd Ave. S	9	2.1

Of the 31 signalized intersections within the four pilot study segments, 26 of the intersections will be AVI/TSP equipped, and 11 were selected for detailed field studies. The selection of the intersections for detailed field studies were based on a number of criteria including:

- were undersaturated (based on off-line analysis and local agency staff observations);
- represented a diversity in number and variety of signal phases;

- resulted in at least two study intersections being studied during the A.M.-, midday-, and P.M.-peak periods for 2-phase, 8-phase, and split phase signal operation;
- were not overly manpower intensive;
- could assure a high degree of accuracy in the data collection effort;
- provided at least two study intersections in each segment during each peak period; and
- maintained diversity between Aurora and Rainier when studying intersections with different signal phasing.

Measures of Effectiveness and Field Data Collection Techniques

Stakeholder concerns related to traffic impacts, transit impacts, air quality and safety lead to selecting the most appropriate MOEs to address these concerns. These MOEs would need to be (1) collected in the field and (2) produced by the simulation model. Therefore, the MOEs also serve as a specification for selecting an appropriate simulation model. The simulation model has to produce the same MOEs collected in the field since future King County DOT implementations will rely more on simulation to address stakeholder concerns than field studies.

Based on stakeholder concerns, nine MOEs will be measured to assess the impact of TSP. These MOEs will be reported for individual intersections and entire segments as appropriate. Segment MOEs, however, will be based solely on observations made at study intersections. Therefore, for a given time period, a segment MOE may only be based on two signalized intersections.

MOEs will be measured during two field studies; first without TSP (i.e., “before” study) and second with TSP (i.e., “after” study). These field studies will be conducted during at least one 2-hour peak period representing either the A.M.-, mid-day, and/or P.M.-peak periods over multiple days. The specific 2-hour peak periods are:

- A.M.-peak period: 7:00 a.m. to 9:00 a.m.
- Midday-peak period: 11:30 a.m. to 1:30 p.m.
- P.M.-peak period: 4:00 p.m. to 6:00 p.m.

For reasonably powerful statistical tests (a high likelihood of detecting before and after differences of relatively small magnitudes) yet manageable from a data collection standpoint, at least 30 AVI-equipped buses (total both directions) have to pass through each study intersection when the MOEs are being measured. Since 30 buses will not be observed during one 2-hour study period, studies will have to be performed over multiple days. MOEs collected over multiple days will be combined to arrive at a single value.

The nine MOEs selected are: (1) intersection control delay, (2) minor movement delay, (3) minor movement cycle failures, (4) bus travel time, (5) bus schedule reliability, (6) intersection bus delay, (7) intersection person delay, (8) vehicle emissions, and (9) accidents. The following sections briefly discuss each MOE and the proposed field data collection technique.

MOE #1: Intersection Control Delay

Intersection control delay (2) data will be measured at selected study intersections when TSP is deactivated to simulate “before” conditions and again when TSP is activated for the “after” condition. Delay will be measured based on direct observation of “vehicle-in-queue” counts. This method normally requires two field personnel per lane group surveyed according to the draft 1997 Highway Capacity Manual.

Since the delay studies will be conducted over multiple days, all delay data for a specified period will be combined to arrive at a single delay value for each intersection. A segment value for average intersection delay will be determined by weighting the delay values at the study intersections according to intersection volume. Therefore, the average intersection delay for each segment will not be based on all signalized intersections along the segment, only the intersections where field data is collected. In summary, intersection control delay (seconds/vehicle) will be reported for each study intersection and segment.

MOE #2: Minor Movement Delay

One of the primary stakeholder interests is the impact that TSP will have on minor movements. Minor movements, as defined here, include: (1) all cross-street movements and (2) protected main-street left turns. The basic TSP operating strategy is to selectively reduce green time for the minor movements and then provide this time to the transit corridor when an AVI-equipped bus approaches an intersection. In so doing, these minor movements are expected to be most noticeably impacted by TSP.

To assess TSP impacts on the minor movements, delay to these movements will be evaluated. Fortunately, delay for each of the minor movements is already captured in the intersection control delay studies. Delay for each minor movement will be weighted according to its volume to compute an average minor movement delay for each study intersection. A similar weighting procedure will be used to determine a corridor delay value for the minor movements. Therefore, minor movement delay (seconds/vehicle) will be calculated for (1) each study intersection and (2) the corridor.

MOE #3: Minor Movement Cycle Failures

Minor movement cycle failures occur when vehicles arrive on the red signal and are unable to clear the intersection during the following green signal. These motorists will typically have to wait an additional signal cycle to clear the intersection. Minor movement cycle failures could be a result of TSP truncating the minor movement green and will likely be the most noticeable change, if any, to the motoring public (11). Observers conducting the intersection control delay studies will record the number of minor movement vehicles “caught” in each cycle failure. Since this data will be recorded over multiple days, the number of vehicles will be averaged per hour and by minor movement to arrive at an intersection value. Similar averages will be determined for each segment. Only a limited number of cycle failures should exist in the before study since the selected intersections are under capacity. The average number of minor movement vehicles caught in cycle failures (vehicles/hour) will be reported for each study intersection and segment.

MOE #4: Bus Travel Times

Besides average person delay at intersections, bus travel times are another key measure to assess the impact of TSP. Average travel time data will be collected for each bus route through on-board data collectors. The data collectors will record the times when the bus: (1) stops at a signalized intersection (i.e., arrives at the back of the queue); (2) passes the stop line (intersecting curb line may be easier for the data collector to identify than the stop line); (3) stops at a bus stop; and (4) departs the bus stop. Operators and riders will be instructed that scheduled timepoints along the corridor segments will become “estimated” timepoints. The intent will be to allow transit to take full advantage of the TSP travel time improvements during the test as well as serve as a basis for future schedule modifications.

TSP does not affect dwell times. Therefore, dwell times (time between #3 and #4 above) will be subtracted from the travel time data. Subtracting dwell times eliminates a variable that could cloud the results of TSP’s impact on bus travel times. Although dwell times are eliminated, the acceleration and deceleration delay that occurs at each stop is not. Identifying when the bus begins to decelerate for a stop and when it returns to its normal cruising speed is impractical to identify from a data collector’s perspective and therefore will not be eliminated.

If an incident is encountered within the corridor, data collectors will record the location of the incident and the time when the incident first began to affect the travel time. Incident affected travel times will either be eliminated or adjusted based on comparisons to travel times collected on other days at the same time.

Bus travel times studies will occur over multiple days concurrent with the intersection control delay studies. Travel times will be averaged over the peak hour and combined for both directions to arrive at a segment travel time. The segment travel times will then be used to assess the impact of TSP on bus travel times. Metro AVI data will be used to collect travel time data between TSP intersections (simultaneously with on-board data collection) to serve as a backup database. The MOE used to assess the impact of TSP on bus travel times is segment bus travel time (seconds).

MOE #5: Bus Schedule Reliability

Standard deviations will be computed for the segment travel times to compare bus schedule reliability with and without TSP. Even if no significant decrease in average travel times is detected after TSP implementation, schedule reliability may improve if the variation in travel times, as measured by the standard deviation, decreases. In summary, bus schedule reliability will be assessed according to the standard deviation (seconds) observed in bus travel times through each segment.

MOE #6: Intersection Bus Delay

Average bus intersection delay will be collected through the on-board data collectors during the travel time studies. Basically, bus delay is the time difference between when the bus stops at a signalized intersection (i.e., back of queue) and the time it passes the stop line. At least 30 bus delay observations will be recorded at each study intersection. These delay values will be averaged to determine an average bus intersection delay value (seconds/bus). Similarly, bus delays at all study intersections will be averaged to derive an average bus delay value for each segment.

Intersection bus delay and the number of times that an AVI-equipped bus stops at each signalized intersection will be compared in the evaluation. Bus delay data (seconds/vehicle) and stops (stops/intersection) will be reported for each intersection and segment.

MOE #7: Average Person Delay

The primary cause of traffic congestion and delay along an arterial street are signalized intersections. The key MOE for assessing the extent to which a TSP operational strategy optimizes signal operations to produce an overall benefit is average person delay. Changes in the average person delay experienced at intersections before and after TSP can be used to assess whether or not TSP improves person movement by providing an overall delay savings.

Average person delay is estimated by combining intersection control delay, intersection bus delay, average automobile occupancy, and average bus occupancy. These statistics are used to estimate average person delay (seconds/person) experienced at each study intersection and for each segment.

Average person delay per intersection is calculated using a weighted average based on vehicle occupancy:

Average Person Delay per Intersection (seconds/person) =

[(Average General Purpose Traffic Delay x Traffic Volume x Average Vehicle Occupancy) +
(Average Bus Delay x Bus Volume x Bus Occupancy)] /
[(Traffic Volume x Average Vehicle Occupancy) + (Bus Volume x Average Bus Occupancy)]

MOE #8: Vehicle Emissions

Air quality benefits of TSP are expected to be derived from the possible long-term shift of people from autos to transit. Total vehicle emissions are not expected to be significantly reduced immediately with the advent of TSP, particularly since TSP is not expected to impact transit demand or travel mode decisions in the short term. Nonetheless, estimates of the average change in vehicle emissions (CO and NOx) resulting from TSP will be calculated for each segment.

Simulation will be used to measure air quality impacts resulting from TSP implementation on a segment basis. Given the short evaluation period, changes resulting from TSP are not expected to result in an increase in either of the emission components (CO and NOx). Therefore, a separate assessment using an air quality model to assess the ambient emission levels before and after TSP implementation is not expected to be necessary.

MOE #9: Accidents

Although accident frequency is not expected to change as a result of TSP, data regarding the numbers and types of intersection accidents provides the basis for a safety MOE to evaluate this expectation. Accident data are continuously recorded by the Seattle, King County, and Washington State DOTS. Accident rates, expressed as accidents per million entering vehicles (MEV), will be computed for each signalized intersection. Accident data will also be summarized by type of accident and vehicle type. In regard to accident type, before and after comparisons will be made between percentages for rear-end, right-angle, and left-turn accidents for each corridor. For vehicle type, comparisons will be made between accident rates involving buses. Since the frequency of bus-involved accidents is expected to be small as compared to the total number of accidents, the resulting bus accident rate will be multiplied by 10 to arrive at a more meaningful number. Before data will consist of these tabulated rates over a one-year period prior to TSP operation. After data will consist of the same tabulated rates for a one-year duration after TSP implementation.

Statistical Analysis

Traffic conditions can be highly variable. A very real danger in the data collection process is that the time period during which data is collected and/or the data itself does not represent typical conditions. Therefore, statistical validity is very important in the analysis of TSP. The data collection efforts specified for the King County Demonstration Project try to address this concern while also realizing that certain data are costly and time consuming to collect in ideal quantities and/or levels of detail.

A large volume of data will be generated during the TSP assessment process for both before and after studies. As a result, there will be a considerable amount of data sorting, compiling and grouping done before any statistical tests are conducted. Much of the assessment data supporting conclusions will require relatively simple descriptive statistic calculations, such as averages, standard deviations, and percent changes.

In addition to the descriptive statistics, the paired t-test will be used to compare means of two measured variables. A paired t-test is used when the comparisons do not involve two independently drawn samples of observations but rather changes in one sample of observations where each individual observation in the “before” situation is paired to the same observation in the “after” situation. The paired t-test looks at the average difference and the variability in the individual observations differences to assess whether they are the result of random chance or the “change event” because their magnitude exceeds the differences that would be attributable to random chance. A two-tailed t-test with a 0.05 alpha-level (95 percent confidence level) will be used. A two-tailed t-test considers both possibilities that the after case may be either (1) greater than or (2) less than the before case.

The number of observations for each sample condition is the single most critical factor affecting the statistical reliability of t-tests. Although the ability to use paired t-tests improves small sample situations, like intersection delay data, there is still some risk of concluding that any before and after differences are due only to random error when in fact TSP may have had a significant impact. Unfortunately, there is no way to assess the level of this risk regarding false conclusions due to small sample sizes prior to examining the dispersion or variability of the sample data itself. To reduce the potential of erroneous conclusions, the number of sample observations is increased to a minimum of 30 transit buses during each before and after study period. This sample size increases the power or statistical reliability of the test.

Simulation

In this initial assessment methodology, a considerable amount of resources are directed toward field studies to evaluate TSP. Assessing the impact of TSP under actual roadway conditions is essential for stakeholders to have confidence in the evaluation results. Field study results also provide a means to validate simulation models. Future TSP implementations, however, are expected to rely more on simulation in order to reduce evaluation costs while adequately addressing stakeholder concerns.

As mentioned previously, simulation requires the evaluation of the same MOEs as outlined in the field data component to the Impact Assessment Methodology. Details regarding the application of simulation in the assessment methodology are addressed in the following three sections.

- Benefits and limitations of simulation
- The TSP computational analysis software suite specified for this demonstration project
- Validation.

Benefits and Limitations of Simulation

Simulation does provide numerous benefits when compared to field studies. Discussing the benefits, however, would not be fair unless its limitations are also discussed.

Benefits

The primary benefits of simulation and the reasons for a greater reliance on simulation to evaluate future TSP implementations are:

1. Reduced costs,
2. Diminished risk,
3. Increased study control, and
4. Improved communication through animation.

The average cost to collect intersection control delay at any one of the 31 study intersections is approximately $7,400. This estimate is based on the following: three peak periods, 2-hour peak periods, two to five days of data collection, six to 10 people per intersection, and $30 per fully burdened man-hour. A sample size of 30 buses passing through each study intersection is a requirement of the statistical tests. Since this frequency does not occur during one study period, data collection occurs over multiple days. The number of intersection approaches and intersection complexity dictates the number of data collectors. Simulating the four study segments, on the other hand, is estimated at $49,000 ($35,000 for network and TSP coding and $14,000 for turning movement counts) or approximately $1,580 per intersection. Therefore, based on these costs, simulation provides cost savings of approximately 79 percent when compared to field data collection. This savings is considered conservative since data collector training and transit agency staff time to perform on-board travel time studies is not included in the delay study costs. Although the estimated savings only apply to this project, it does exemplify the savings offered by simulation.

Simulation should and will be used as a design tool to answer "what if" questions (e.g., what if the TSP operating strategy is modified?, what if the transit headway is reduced?). Utilizing simulation in this manner, produces additional cost savings. Simulation models can test these alternatives with only minor costs associated with modifying the model as compared to the costs to implement these changes in the field and then undertake an extensive field data collection effort. Similarly, simulation can and will be used as a design tool to answer a variety of questions associated with projected future geometric and operational conditions that are impossible to model in the field.

Field studies add a considerable amount of monetary risk in terms of resources, unpredictable weather, and traffic incidents. Field studies used in this project rely heavily on people to collect data. For example, to collect intersection control delay requires anywhere from six to 10 people per intersection. Risk enters in the form of making sure everyone arrives at the study site on time. If the field study is short a person, the study may have to be postponed which can delay a project. The people who arrive, however, still need to be paid for their time. Inclimate weather occurring after the field study has started may also lead to postponing the study; again, resulting in increased costs and delays. Traffic incidents within the study area or on adjacent routes that cause diversion to the study area can diminish the integrity of collected data. Transit operator behavior related to on-time performance practices may also vary affecting study results. The severity of the incident may require collecting data again. Simulation eliminates these risks.

When performing before and after field studies, the ideal situation is to have the exact same field conditions during the before and after study except for the variable being studied. Although some control can be incorporated into field studies, other factors may still influence the data leading to erroneous conclusions. These factors can include: traffic volume changes, modified signal timings that were not communicated to the study team, revised transit schedules, or human error. Simulation eliminates these outside influences by permitting the user to change only the factor being studied, in this case, TSP.

Probably the most positive aspect of simulation models is their ability to graphically illustrate traffic conditions through animation. Although different simulation models have different capabilities in this area, animation makes it easier to communicate complex project aspects to decision-makers and the public. This feature is extremely valuable when the project involves a considerable change in roadway geometry or the implementation of a new operational strategy.

Limitations

Simulation also possesses some limitations when compared to field data. These limitations include:

1. Ability to replicate observed traffic conditions; and
2. Building stakeholder confidence.

When developing any simulation model, the generally accepted tolerance is to be within +/- 10 percent of actual field conditions (traffic volumes and travel times). Achieving this tolerance is not always possible. The modeler has to determine the point at which continued calibration does not yield significant results relative to the cost and effort. Not achieving this tolerance can call the model and its results into question.

If stakeholders do not have confidence in the simulation model and its results, the modeling effort provides no value to the project. Developing this confidence is typically a challenge on any project where simulation is used to address stakeholder concerns. This sentiment is most probably related to the previous point about the model's ability to replicate observed traffic conditions, even when the above tolerances are achieved. Adding to this sentiment is the usual unfamiliarity with the underlying model assumptions. Stakeholder confidence in the model's ability, however, can be improved by clearly communicating model assumptions to all stakeholders and providing opportunities (e.g., workshops) for them to become more familiar with the model. In addition, being able to provide unbiased references that the stakeholders can call upon to ask questions about their satisfaction with the model's previous use can also increase stakeholder confidence.

Overview of TSP Computational Analysis Suite

For the King County Demonstration Project, a software suite was specified for analyzing and simulating the pilot study segments that would integrate computational models to both simulate traffic and TSP operation as well as utilize the analytical power of highway capacity software. The TSP computational analysis software suite (refer to Figure 2) combines a microscopic traffic and transit *simulation* model[1] with a traffic analysis software *integrator*[2] and a Highway Capacity Manual *(HCM)*[3] analysis tool. The software suite allows for simulating as well as analyzing TSP and its impact on traffic and transit operations.

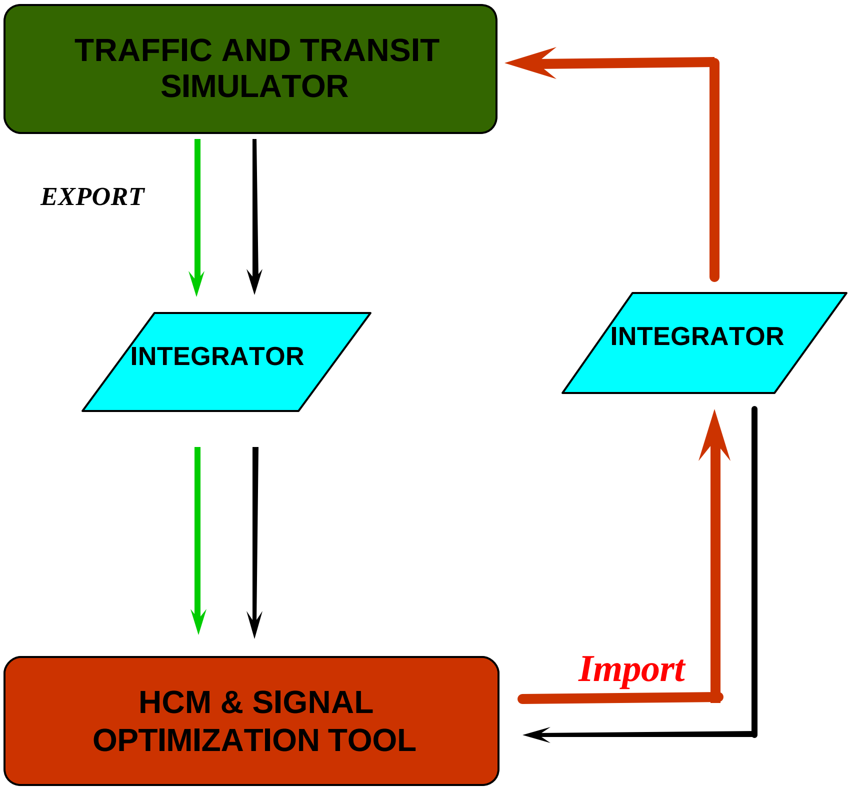

Figure 2. Software Suite Interface

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[1] VISSIM,
[2] TEAPAC
[3] SIGNAL94

The stakeholders chose a microscopic, time step and driver behavior based simulation model developed to model urban traffic and public transit operations. The program can analyze traffic and transit operations under constraints such as lane configuration, traffic composition, traffic signals, transit stops, and transit schedules. The simulation model can also be used to test the effectiveness of various TSP parameters (green extension, early return to green, and detector calling points) thus making it a useful tool for the evaluation of various alternatives based on transportation engineering and planning measures of effectiveness. In order to accurately reflect algorithms of traffic signal controllers, the simulation model uses two different programs, a traffic simulator and an external signal state generator, exchanging detector calls and signal status through an interface. The traffic simulator is a microscopic traffic flow simulation model including car following and lane change logic. The signal state generator is a signal control software polling detector information from the traffic simulator on a second by second basis. It then determines the signal status for the following second and gives this information back to the traffic simulator. The external signal state generator can be programmed to simulate any form of signal control algorithm including TSP and railroad preemption. The integration software allows the simulation model and the HCM model to share common data and test various control strategies as well as optimize lane configurations and signal timing

Model Requirements

Several data will be collected and used as input into the TSP Computational Analysis Suite. The software suite will require information on roadway characteristics, vehicle composition, traffic and signal controller operations, transit operations and facilities, pedestrians and vehicle emission rates. The specific information used by the software suite is described below, and intended to provide a scope of information required to develop simulation models and to test the effectiveness of different TSP strategies prior to their implementation in the field. Data required as software input include:

- Base map (aerial photograph) to scale
- Hourly traffic volumes per movement (5 min. to 60 min. intervals)
- Truck percentage and vehicle occupancy per approach
- HOV percentage including vehicle occupancy (Simulation only)
- Pedestrian volumes
- Average speeds or posted speed limits (Simulation only)
- Grades (HCM only)
- Vehicle arrival type (HCM only)
- Ideal saturation flow rates (HCM only)
- Stop/yield sign locations (Simulation only)
- Right turn on red volume (HCM only)
- Signal timing including cycle length, phasing, force-offs, offsets, minimum gap times, maximum green times, amber times, etc.
- Detector sizes and locations (Simulation only)

- Transit stops including mean and standard deviation dwell times (Simulation only)
- Transit routes including vehicle length, acceleration and deceleration, stops served, schedule and vehicle occupancy (Simulation only)
- Bus check-in/check-out locations (Simulation only)
- Maximum green extensions and early greens (Simulation only)
- Transit signal priority logic (Simulation only)
- Stopping buses per hour (HCM only)
- CO and NO_x emission rates by vehicle class and speed (Simulation only)

Validation

Stakeholder feedback is necessary to develop appropriate steps to validate the model. Increasing their comfort level is crucial for the model to gain acceptance and be relied on more heavily for future evaluations. At this point, the following field data will be used to validate the model: turning movement volumes, transit travel times, and intersection control delay. A simulation model is generally considered valid when simulation data is within +/- 10 percent of field data. This tolerance will be used to assess the model's ability to replicate field conditions. On a final note, as the simulation portion of the project approaches, stakeholder's feedback regarding validation is expected to increase. Increased feedback will likely lead to additional steps to validate the model.

CONCLUSIONS AND FINDINGS

Primary conclusions and findings emerged developing the impact assessment methodology for the King County Demonstration Project are in regard to stakeholder involvement and comparisons between field studies and simulation.

Major conclusions and findings include:

- Stakeholders were the driving forces behind the design of an impact assessment methodology to evaluate and compare TSP operations between study segments. Their concerns lead to identifying the MOEs and corresponding field data collection techniques.
- Stakeholder concerns were in general related to four areas: (1) traffic impacts, (2) transit impacts, (3) air quality, and (4) safety.
- All jurisdictions demonstrated a concern regarding cross-street delay experienced resulting from TSP along the mainline.
- Simulation was chosen as a critical element in the impact assessment methodology due to its advantages over field studies in regard to: cost, risk, study control, and communicating impacts to policy makers.
- Simulation is estimated to produce a conservative 79 percent cost savings when compared to field studies.
- Future TSP implementations are expected (stakeholder acceptance is critical) to rely more on simulation than field studies to reduce evaluation costs while adequately addressing stakeholder concerns.

RECOMMENDATIONS

A considerable amount of experience was gained through developing a TSP impact assessment methodology for the King County Demonstration Project. The experience has lead to the following recommendations:

1. Develop a formal impact assessment methodology that is accepted by stakeholders prior to actually measuring TSP impacts. Formalizing the methodology and gaining stakeholder acceptance minimizes the risk of omitting steps necessary to address stakeholder concerns. Consequently, the possibility of increased costs and project delays are reduced.

2. Incorporate a stronger simulation role into impact assessment methodologies. Although extensive field studies are initially used in the King County Demonstration Project to increase stakeholder comfort with TSP and the simulation model's ability to replicate field conditions, funds are not available for such extensive evaluations of future TSP implementations. As discussed in this paper, simulation models accepted by stakeholders provide a cost-effective and flexible alternative to field studies.

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