

# **Simulation of Transit Signal Priority Using the NTCIP Architecture**

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## **Abstract**

*Transit Signal Priority (TSP) is an important element of Bus Rapid Transit (BRT) that involves coordinated efforts between transit vehicle detection systems, traffic signal control systems, and communication technologies. Successful deployment of TSP requires thorough laboratory evaluation through simulation before field implementation. This paper presents the development and application of a simulation model specifically designed for the design and evaluation of TSP systems. The proposed simulation tool models in detail all the TSP components in accordance with the National Transportation Communications for ITS Protocol (NTCIP) standard for TSP systems. The study is intended to shed light on how the variety of TSP elements can be addressed in microscopic simulation in a structured and systematic fashion. Sample applications of the model on a real-life arterial corridor in California demonstrate its capabilities and features.*

## **Introduction**

Although past research and experience have demonstrated the benefits of Transit Signal Priority (TSP) to transit vehicles, skepticism still remains regarding its effectiveness among various parties. To address these skepticisms, evaluation

methodologies that satisfy the concerns of a diverse set of stakeholders are needed (Gifford 2001). While field evaluation provides real world assessment, traffic simulation is advantageous in conducting “what if” studies before implementation and “before and after” analysis in evaluation. It is also a more economical way as compared to the cost of field evaluation.

A TSP system is difficult to address in traffic simulation (Sunkari et al. 1995). Basic requirements for simulating TSP involve emulating the logic of fixed time/actuated traffic signals under the normal operation and during transit signal priority, detection of bus at the check-in and check-out points, priority generator, priority server, communication links between buses and traffic signals, bus movements in the traffic stream, and the dwell time at bus stops. Advanced features needed to be modeled include but are not limited to adaptive signal control, Automatic Vehicle Location (AVL) systems, additional priority treatment options (e.g., queue jump, transit phase, recall, green hold etc), on-line event monitor to record and report the status of buses and signals, bus arrival time predictor, on-line bus schedule checking, and passenger counting systems.

TSP impact analysis relies greatly on simulation (Smith et al. 2005, Dale et al. 2000). Several commercial simulation software packages such as VISSIM (PTV 2003), CORSIM (FHWA, 2003), and PAMRAMICS (Quastone 2004) provide, to some extent, functions for simulating traffic signals and transit vehicles. Evaluation of TSP has been conducted mainly through these simulation tools. Recent examples of this include the work of Balke et al. (2000), Davol (2002), Shalaby et al. (2003), Dion et al. (2004), and Ngan et al. (2004) who used CORSIM, PARAMICS, and VISSIM to evaluate the effectiveness of the early green and the extended green strategy.

Most simulation models currently available lack most of the characteristics and capabilities for realistically modeling real-life TSP systems. Application of oversimplified simulation models may draw inconvincible conclusions and sometimes mislead the implementation. In addition, the extensive use of AVL data in transit management, planning, and operation has presented a challenge to the development and application of next generation traffic simulation tools (Chu et al. 2004). A new NTCIP standard (NEMA/ITE/AASHTO 2005) is being developed that aims to define communication protocols and the logical architecture of a transit signal priority system. It is extremely important for the design of future TSP simulation models to comply with the NTCIP definitions so that the diversity of the transit signal priority systems can be addressed in a systematic manner.

This paper presents the development and application of a simulation model specifically designed for the design and evaluation of various TSP systems. The proposed simulation tool models virtually all the TSP components in accordance with the NTCIP definitions. The model was developed in support of a study for developing advanced bus signal priority strategies sponsored by the California Department of Transportation (Caltrans) in cooperation with the San Mateo Transit District (SamTrans) in the San Francisco Bay Area.

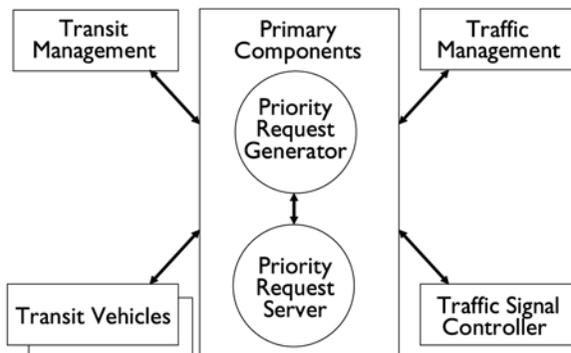
## Logical and Physical Structure of a TSP System

### Logical Structure of TSP

NTCIP provides both communication protocols and the vocabulary (called objects) necessary to allow electronic traffic control equipment from different manufacturers to operate with each other as a system. Two main NTCIP standards that are related to traffic signal control and transit signal priority control are NTCIP 1202 and NTCIP 1211. The former defines the commands, responses and information necessary for the management and control of actuated traffic signal controllers. The NTCIP 1211 Signal Control Priority standard provides the framework and communication protocols for the design of a signal priority system.

One of the significant contributions of NTCIP 1211, aside from the description of the “computer objects” for communication, is the definition of the functional entities of a TSP system. As shown in Figure 1, the logical structure of a TSP system is composed of a Priority Request Generator (PRG), a Priority Request Server (PRS), and a Coordinator. The primary functions of the PRG are to determine the

**Figure 1. Logical Structure of a TSP System (NTCIP 1211)**



necessity for generating a priority request, to estimate priority service time, and to communicate the request to the PRS. The final decision is made in the PRS. It receives priority requests from multiple PRGs, processes the requests based on importance and priority, and sends the selected requests to the traffic signal controller for priority operation.

### ***Physical Structure of TSP***

According to the Intelligent Transportation Society of America (ITSA) (2003), a physical TSP system is composed of three major components: the vehicle detection system that detects transit vehicles and generates priority requests, the traffic signal control system that receives and processes the request for priority at the intersections, and the communications system that links the vehicle detection system with the traffic signal control system.

The bus detection system is further categorized into point detection or selective vehicle detection (SVD), zone detection, and area detection systems. As illustrated in Figure 2, inductive loops and radio frequency (RF) tags with readers are two typical point detection devices. The vehicle-to-controller communication is achieved through on-vehicle equipment (either a transponder or a RF tag) and a road-side receiver. The on-vehicle device contains a data packet that is sent to the receiver when a bus passes through the detection point. Upon the detection of a transit vehicle, signal priority can be operated at the local or the central level.

Unlike point detection devices that sense the presence of transit vehicles at fixed locations, zone and area detectors may extend the detection area to a certain distance from the intersection. The Opticom<sup>TM</sup> system from 3M is probably the most widely implemented traffic signal priority control system that enables signal priority operation to both emergency and transit vehicles. As shown in Figure 3(a), the system works by an emitter mounted on the vehicle. When activated, it sends an optical flashing signal at a certain rate and at an exact duration, emergency vehicles and buses are differentiated by different flashing frequencies. Figure 3(b) depicts an AVL based system, in which a bus provides schedule adherence and passenger information along with the priority request continuously to the traffic/transit management center, where the central computer in return makes decision upon whether and how the transit vehicle should be served.

A major distinction between the zone/area detection based and the point detection/SVD-based TSP lies in the control logic with regard to the initiation time of the priority operation. SVD-based systems initiate the priority operation upon

Figure 2. Point Detection Based TSP Systems

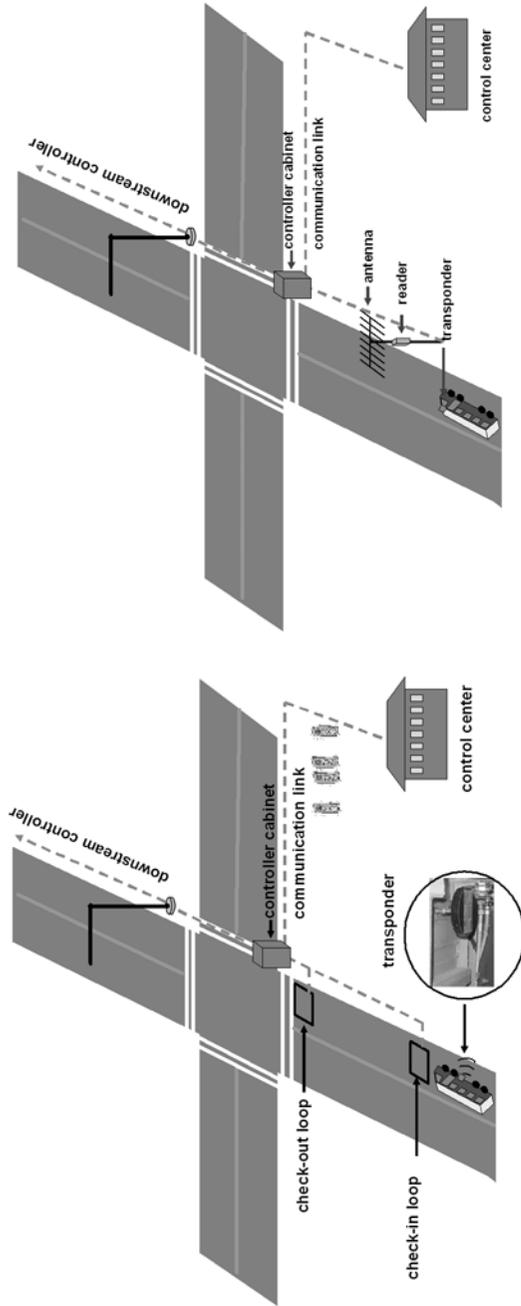
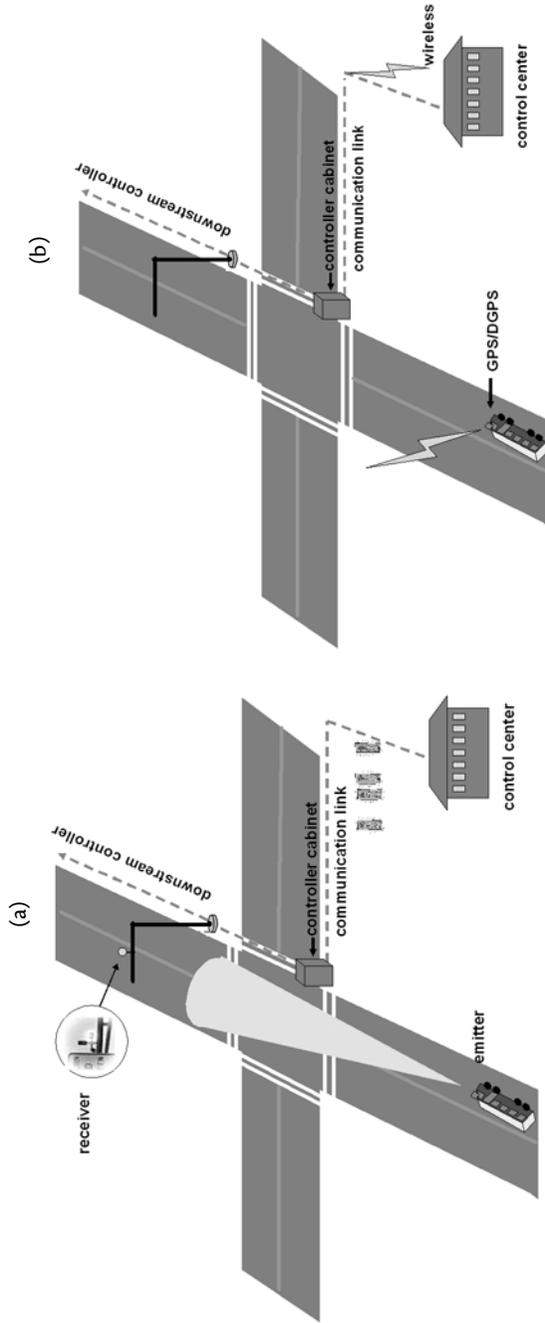


Figure 3. Zone and Area Detection Based TSP Systems



detecting an approaching bus at the single-point location where the detector is located. The AVL-based system has the advantage of placing priority calls at any time while a bus approaches the intersection. As a result, the priority operation may be started at flexible times. It is of great importance for a TSP simulation to be able to realistically represent these two different control configurations.

## **Simulation Design**

### ***Simulation Architecture***

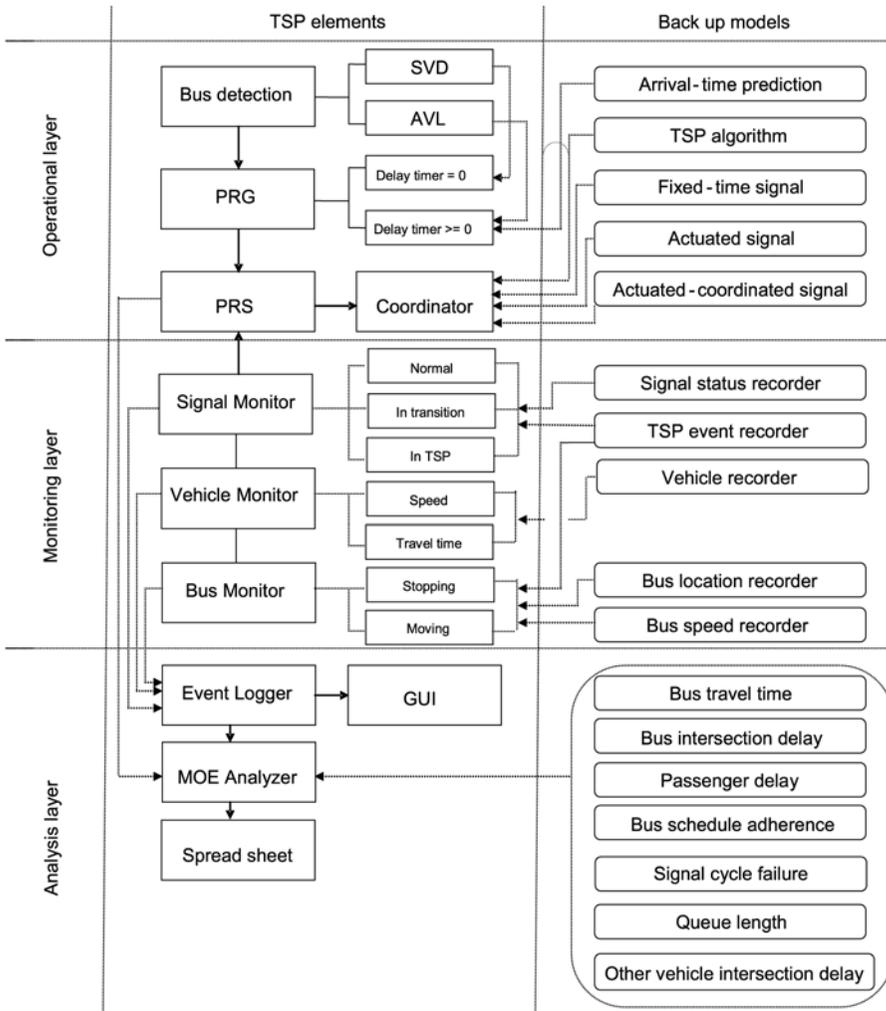
Figure 4 illustrates a recommended architecture design for TSP simulation models. It is composed of three layers with each of them functioning as a dependent element of the whole system in accordance with the definitions described in the foregoing section. The operational layer consists of the bus detection module, the PRG, the PRS, the Coordinator in correspondence to the bus detection system, the communication system/priority requestor and the traffic signal control system.

The monitoring layer consists of various virtual recorders to record special events during simulation and transfer the information to the Event Logger in the Analysis layer, which is designed to highlight the events through a viewing window and write outputs to the MOE Analyzer. The MOE Analyzer is the analysis module for processing and summarizing the outputs of the measures of effectiveness (MOEs). It obtains outputs from the PRS and the Event Logger and imports the results into spreadsheets for analysis.

Two sub-modules under the bus detection module replicate the SVD-based and the zone/area detection-based-systems separately. The PRS is where the built-in priority control algorithm resides. The time buffer called “delay timer” in PRG is to differentiate the SVD-based systems from AVL-based systems. The default setting is zero, which replicates the instantaneous reaction logic for SVD-based systems. The user selectable scope is from 0 to the length of one signal cycle with the consideration that the priority operation cannot be delayed over one cycle in an AVL-based system. Setting up the “delay timer” is the only decision made at the PRG level.

Most of the functional TSP elements are supported by analytical models that were developed through the development of the simulation model (Liu et al. 2005). Key developments include a recursive least- square approach that estimates bus arrival time at the intersection by using historical and real-time bus movement data, a

**Figure 4. The Functional Architecture of the Simulation Model**



model assisting PRS in selecting the optimal time to initiate priority operations for AVL based systems, and a TSP algorithm defining the built-in control logic.

**The Priority Request Server**

The Priority Request Server is where the priority requests are processed and final decisions are made with regard to whether and how a priority request needs to be

served. It is recommended that all TSP strategies and control policies be defined in the PRS. For instance, the built-in priority logic in this model is defined as the following:

- Signal priority applies to main street phases 2 and 6 and minor street phases 4 and 8.
- One priority service in every other cycle; the cycle following the TSP cycle is considered the transition cycle.
- In case of multiple priority requests, the “first come first serve” principle applies.
- Green extension initiates at the end of a signal phase only if the check-out call has not been received during normal green.
- The minimum guaranteed green of a signal phase equals the *Max (minimum green time | pedestrian interval)*.
- The maximum extension equals 15 percent of the signal cycle in coordinated signal operations and 25 percent in free signal operations and isolated intersections.

### ***Signal, Pedestrian, and Bus Dwell Time***

The signal control module defines various functionalities of virtual signal controllers. At minimum, it should be able to replicate the NEMA eight phase dual-ring control logic. An input interface needs to be provided so that the critical signal timing parameters along with a common signal timing sheet can be read into simulation. The following parameters are required: *Minimum Initial, Passage, Minimum Gap, Maximum Gap, Max Green, Red Clearance, Yellow, Offset, Walk, Flashing Don't Walk*. Optional inputs may include *Max recall, Min Recall* and *Pedestrian Recall*.

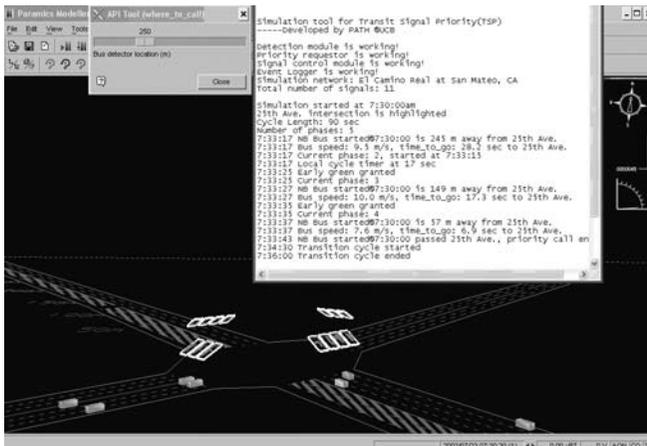
Despite their significant impact on various TSP operations, pedestrians have been ignored in most current TSP simulations due to the complexity of modeling. A recommended approach is to model the pedestrian demand through signal timing parameters. For instance, the *Walk* and *Flashing Don't Walk* in this model were associated with the phases 2, 6, 4, and 8 and could be activated according to a predefined frequency to represent the presence of pedestrians. The default setting assumes that the pedestrians arrive at the intersections following a Poisson distribution. Dwell time for a bus is the time it spends at the bus station for boarding and alighting passengers and is a function of passenger demand and type of passengers (e.g., with bicycle or wheelchair, monthly pass, or pay per trip,

etc). The Poisson distribution is also a suitable representation of bus dwell time (Skabardonis 2000).

### Event Logger

Simulating TSP is a complicated process. The Event Logger allows users to check online whether the simulation is correctly replicating the predefined control logic. As shown in Figure 5, the Event Logger updates to a viewing window the current status of selected signals including current phase, cycle and the local cycle timer, if in coordination. If the AVL is "ON" in the PRG, it updates bus ID and location every second or at a frequency specified by the user. If SVD is "ON," it highlights the time, location and bus ID upon the detection of a bus. If priority requests are present, the Event Logger records and outputs to the window the ID number of the signal requested for priority, bus check-in time, requested priority type, the moment when the priority process is initiated and the bus check-out time. A priority request may be rejected for a signal in transition and/or during the pedestrian interval. In either case, the Event Logger reports the reason for the rejection.

Figure 5. Snapshot of the Event Logger



### MOE Analyzer

The MOE analyzer provides a tool to process the simulation output and summarize key statistics of MOEs to facilitate the evaluation of proposed TSP strategies.

The following MOEs are involved in the proposed simulation and recommended for consideration in TSP simulation models: bus travel time; bus intersection delay; passenger delay; bus number of stops at signalized intersections; vehicle intersection delay; vehicle number of stops at signalized intersections; signal cycle failure; queue length; and bus headway deviation.

To provide bus MOEs, the simulation needs to record the times (1) when a bus is released into the network (2) when a bus stops at a signalized intersection (3) when a bus stops at a bus stop (4) when a bus leaves a bus stop (5) when a bus passes the stop line of an intersection and (6) when a bus ends the trip. The link travel time of bus  $k$  on the link  $(i,j)$ , say,  $T_{ij}^B(k)$ , is therefore defined as the time difference between the two time stamps recorded when the bus passes the intersection  $i$  and the intersection  $j$ . Hence, the total link travel time for all buses during the simulation becomes  $\sum_k T_{ij}^B(k)$ .

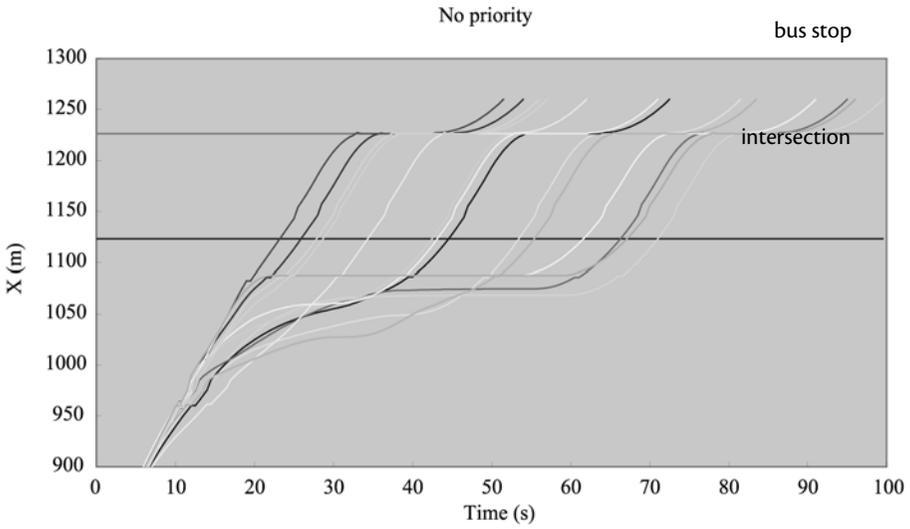
Figure 6 gives a sample output for two sets of bus trajectories obtained from the proposed simulation model.

## **Model Application**

The sample model was developed in support of a study for developing advanced traffic signal priority strategies, a project sponsored by the California Department of Transportation in cooperation with the San Mateo Transit District in the San Francisco Bay Area. As mentioned before, one of the principal distinctions between the SVD-based and the AVL-based TSP system lies in the control logic with regard to the initiation time for the priority operation. The sample application investigates the effect of detector locations (for SVD-based system) and actuation time (for AVL-based system) on the overall performance of TSP.

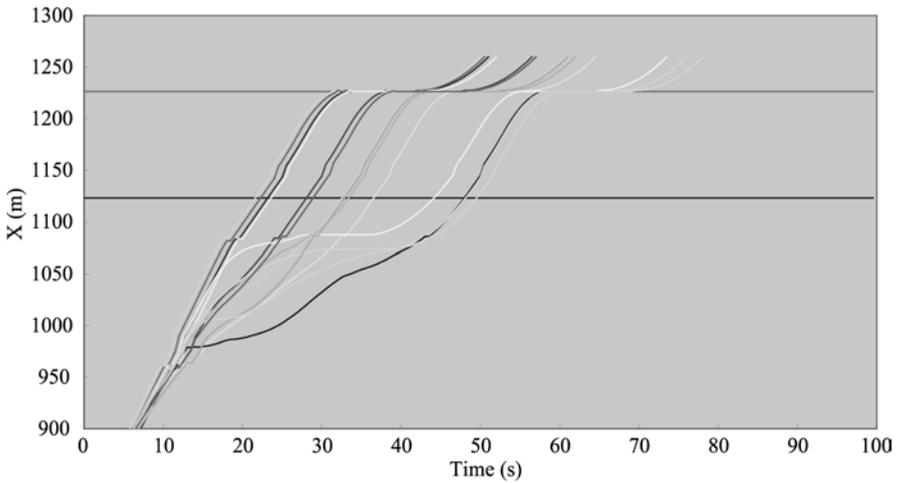
As shown in Figure 7, the test site is comprised of 12 signalized intersections from 2nd Ave. to 28th Ave. to the south of El Camino Real. The traffic signals are vehicle-actuated and coordinated on the El Camino Real. Bus dwell time was defined based on the real data from SamTrans's GPS equipped buses (Liu et al. 2004). The pedestrian demand was emulated by the Walk and Flashing Don't Walk, which were assumed to be activated once on every approach every five signal cycles. The bus frequency was set at 6 buses/hr during the analysis period.

**Figure 6. Sample Bus Trajectories from Simulation**



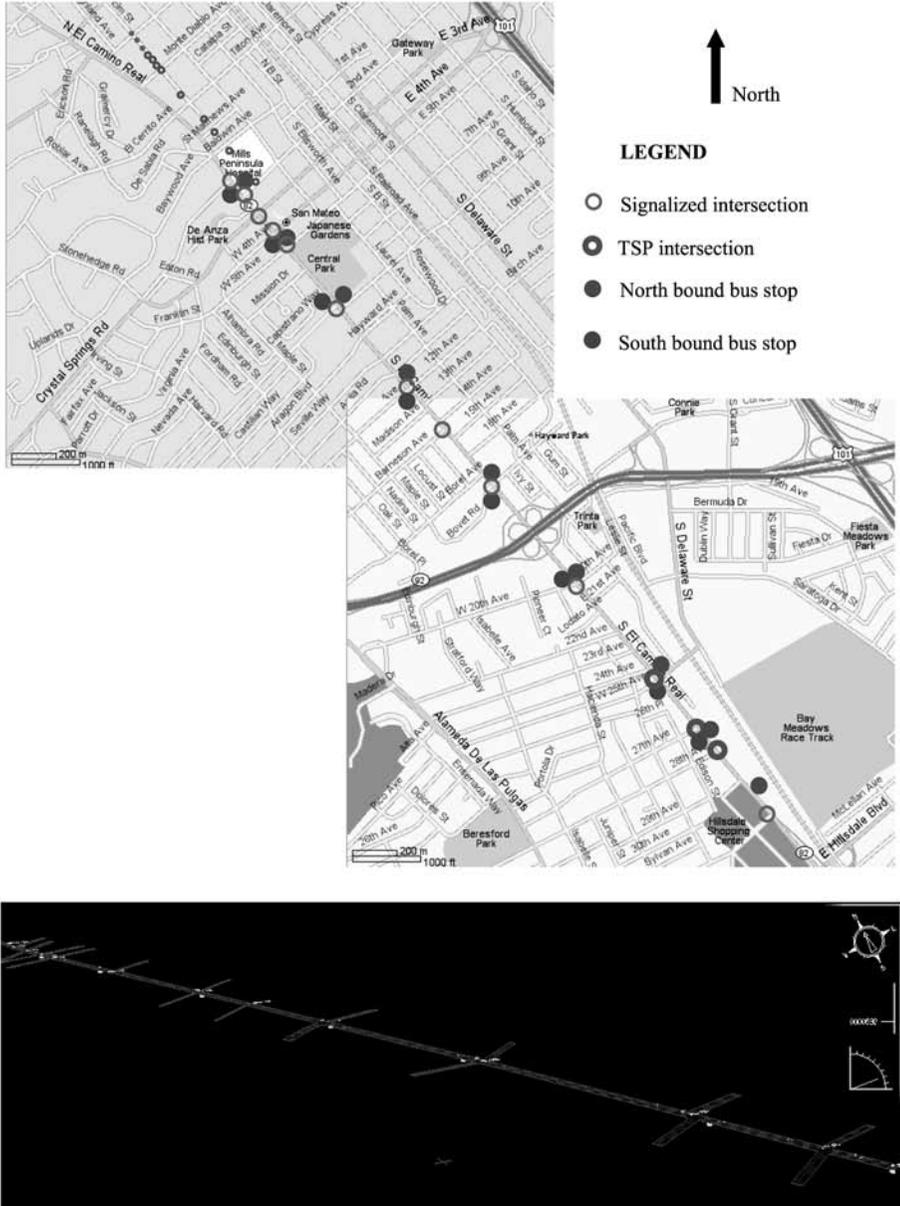
**Without Priority**

Call at 250 meter



**With Priority**

Figure 7. Studied Segment of CA Highway 82



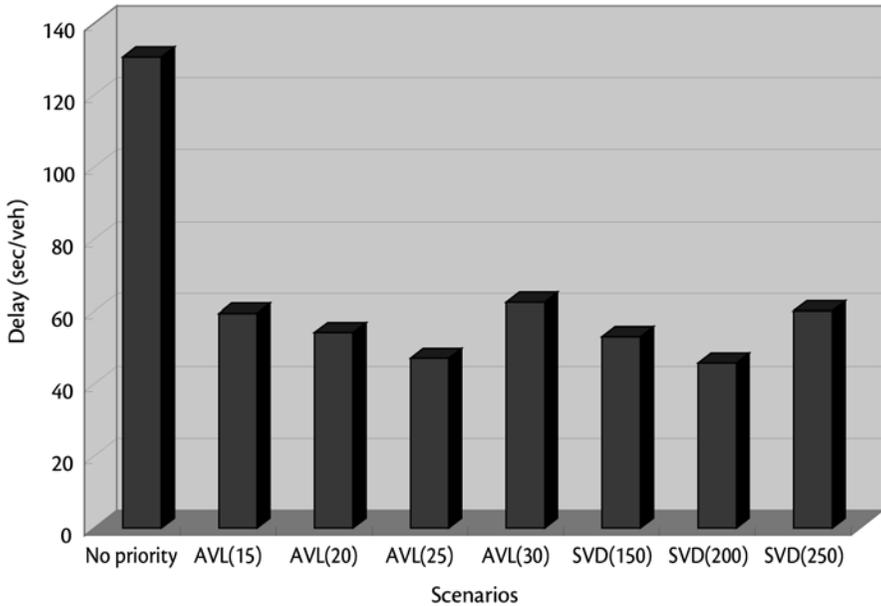
For SVD based simulation, the check-in bus detectors were placed 150 meters, 200 meters, and 250 meters upstream of the intersections, where applicable. If the spacing between two intersections was shorter than 150 meters, the check-out detector of the upstream intersection was used as the check-in detector of the downstream intersection. For the AVL-based approach, priority calls were placed when buses were 15, 20, 25, and 30 seconds away from the intersection. In total, eight scenarios were simulated:

- (1) No priority
- (2) AVL (15) registering priority calls when buses are 15 seconds away from the intersections
- (3) AVL (20) registering priority calls when buses are 20 seconds away from the intersections
- (4) AVL (25) registering priority calls when buses are 25 seconds away from the intersections
- (5) AVL (30) registering priority calls when buses are 30 seconds away from the intersections
- (6) SVD(150) placing bus detectors 150 meters upstream the intersections
- (7) SVD(200) placing bus detectors 200 meters upstream the intersections
- (8) SVD(250) placing bus detectors 250 meters upstream the intersections

The result, illustrated in Figure 8, reveals that placing the bus detectors 200 meters upstream of the intersections and triggering the signals when the buses are 25 seconds away from the intersections gave the minimum bus intersection delay. The average vehicle delay on El Camino Real and the cross streets is depicted in Figure 9, which shows that the intersection delay of non-transit vehicles along the arterial and the cross streets do not seem to vary significantly with the various signal priority strategies.

Figure 10 illustrates the effectiveness of various signal priority strategies in terms of the reduced bus headway deviations. Table 1 summarizes the average bus speeds, bus travel times, bus dwell time and signal delay in total bus travel times, and the time savings because of signal priority (in seconds and percent of total travel time).

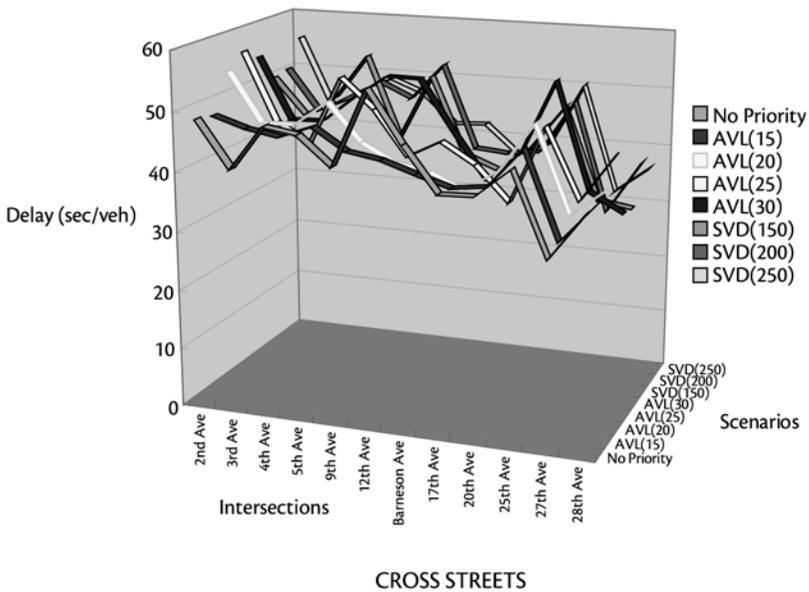
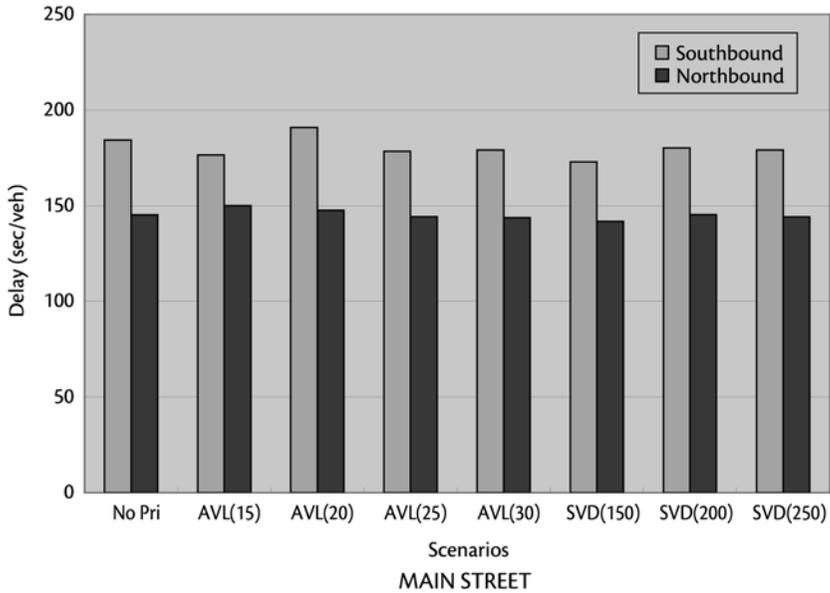
**Figure 8. Average Bus Intersection Delay**



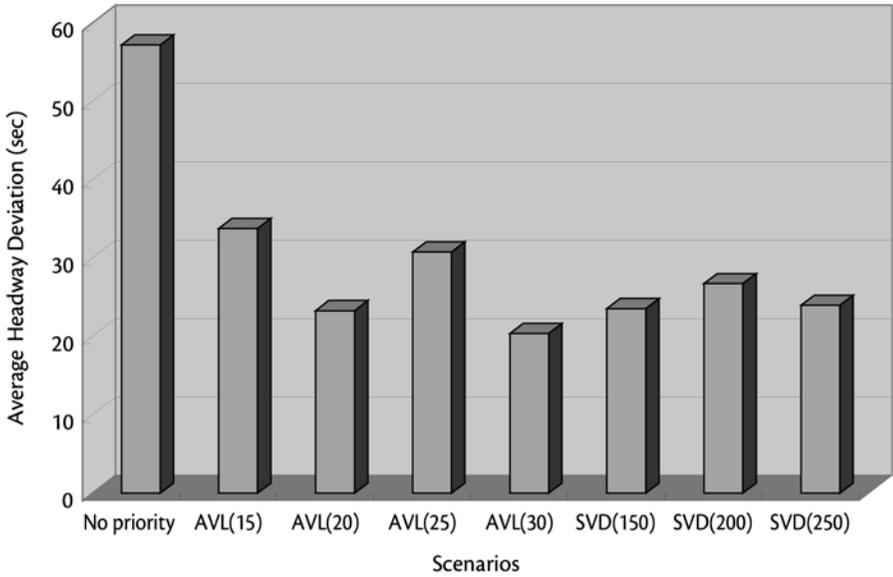
## Conclusions

Although traffic simulation has been widely used in evaluation of TSP systems, the development of TSP simulation models has been approached differently by researchers and traffic engineers on the basis of their specific needs and interpretation of the elements of a TSP system. The development and application of TSP simulation models has been thought of as a project-based function rather than as a systematic process. As a result, many simulation models were created independently, and some of the models were discarded upon completion of the specific projects. The major purpose of the study was to demonstrate how the variety of TSP elements could be organized in microscopic simulation in a structured and systematic fashion in accordance with the NTCIP architecture. The logical and physical infrastructure of a TSP system was interpreted, and recommendations for design were made along with the development and application of the sample simulation model. The advantage of the proposed simulation in modeling both point-detection-based and area-detection-based TSP systems was demonstrated through a sample application to 12 signalized intersections on CA Highway 82.

**Figure 9. Vehicle Intersection Delay**



**Figure 10. Bus Headway Deviation**



**Table 1. Sample MOE Analysis**

Scenarios	Average travel time (sec)	Average Speed (mph)	Dwell time (% of travel time)	Signal delay		Time savings*	
				(sec)	(%)	(sec)	(%)
No priority	576	21	21.7%	131	22.7%	0	0.0%
AVL(15)	505	25	24.8%	60	11.8%	71	12.3%
AVL(20)	509	25	24.5%	54	10.6%	77	13.4%
AVL(25)	492	26	25.4%	47	9.6%	84	14.5%
AVL(30)	508	25	24.6%	63	12.3%	68	11.8%
SVD(150)	498	26	25.1%	53	10.7%	78	13.5%
SVD(200)	491	26	25.5%	46	9.3%	85	14.7%
SVD(250)	505	25	24.7%	60	11.9%	70	12.2%

## Acknowledgements

The authors would like to thank the following for their generous assistance and extensive contributions to our research: Mr. Wei-bin Zhang of the California PATH

program; Sonja Sun of Caltrans' Division of Research and Innovation; Kai Leung of Caltrans' Division of Traffic Operation; Frank Burton of San Mateo Transit District; and Shuaiyu Chen of the TRANSTECH lab of Texas Tech University.

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