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Comprehensive Evaluation on Transit Signal Priority System Impacts Using Field Observed Traffic Data (Phase One)

by

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16. ABSTRACT

To improve the level of Community Transit (CT) services, the South Snohomish Regional Transit Signal Priority (SS-RTSP) project has been launched. To understand the overall benefit of this project, the SS-RTSP system (phase one) was tested and evaluated after the completion of the hardware and software installations on the 164th Street SW street corridor in Snohomish County, Washington State.

In this study, impacts of the SS-RTSP system on both transit and local traffic operations were quantitatively evaluated based on field observed data. A simulation model was also built and calibrated to compute measures of effectiveness that cannot be obtained from field-observed data. With the simulation model and field observed data, the impacts of the SS-RTSP system on both transit and local traffic operations were quantitatively evaluated. Our evaluation results showed that the SS-RTSP system introduced noticeable benefits to transit vehicles, with insignificant negative impacts to local traffic on cross streets. The overall impact of the SS-RTSP system on local traffic of the whole intersection was net benefit.

To improve the performance of the current SS-RTSP system, more transit vehicles can be enabled for TSP eligibility. The average number of granted TSP trips was only 16.96 per day per intersection during the test. Considering that negative impacts of the SS-RTSP on local traffic were not significant, more transit trips can be granted with proper TSP treatment to generate more benefits from the SS-RTSP system. Also, near-side bus stops were found to introduce extra transit delays when TSP was on under certain conditions. Our recommendation is that the TSP treatment of extended green may be disabled at intersections with near-side bus stops to avoid introducing negative impacts on transit vehicles.

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EXECUTIVE SUMMARY

Transit signal priority (TSP) is an operational strategy that facilitates the movement of in-service transit vehicles through signalized intersections. To improve the level of Community Transit (CT) services, the South Snohomish Regional Transit Signal Priority (SS-RTSP) project has been launched. To understand the overall benefit of this project, the SS-RTSP system (phase one) was tested and evaluated after the completion of the hardware and software installations on the 164th Street SW street corridor in Snohomish County.

In this study, impacts of the SS-RTSP system on both transit and local traffic operations were quantitatively evaluated based on field observed data. A simulation model was also built and calibrated to compute measures of effectiveness that cannot be obtained from field-observed data. With the simulation model and field observed data, the impacts of the SS-RTSP system on both transit and local traffic operations were quantitatively evaluated. Our evaluation results showed that the SS-RTSP system introduced noticeable benefits to transit vehicles, with insignificant negative impacts to local traffic on cross streets. The overall impact of the SS-RTSP system on local traffic of the whole intersection was net benefit.

With the SS-RTSP system, transit vehicles can be operated more reliably. The measure of effectiveness (MOE) of Transit Time Match indicated improvements ranging from 0.3 to 3.4 minutes, or 3.9 percent ~ 27.4 percent at the tested transit stops. The mean eastbound corridor travel time of transit vehicles was 6.7 seconds or 4.9 percent shorter for granted trips than the average corridor travel time without TSP. The average intersection travel time of transit vehicles for granted trips at all the four intersections (including both eastbound and westbound directions) was 6.11 seconds or 29.14 percent shorter compared with intersection travel time with TSP off. Because of the saved transit travel time, the SS-RTSP system decreased the overall personal delays. The results showed that the average person delay was reduced by 0.1 second for all the passengers who used the intersections.

The SS-RTSP system increased cost of local traffic on cross streets. The test results showed slight change in vehicle delay, queue length, and signal cycle failure frequency on cross streets. However, the t tests indicated that these changes were not significant after the TSP implementation.

Similarly, the SS-RTSP system introduced slightly longer delays to local traffic on cross streets. However, our evaluation results showed that benefit received by local traffic sharing the same phase with the transit vehicles was more than offsetting the cost of cross street traffic. Consequently, the whole intersection got benefits from the TSP system. The average vehicle delay of all movements of the tested intersections decreased 0.1 second after TSP implementation.

However, phase-one evaluation of the SS-RTSP system was based on a limited amount of data and on a relatively short corridor. Conclusions obtained from this evaluation study may not be applicable to more general conditions of TSP systems.

To improve the performance of the current SS-RTSP system, more transit vehicles can be enabled for TSP eligibility. The average number of granted TSP trips was only 16.96 per day per intersection during the test. Considering that negative impacts of the SS-RTSP on local traffic were not significant, more transit trips can be granted with TSP treatment to generate more benefits from the SS-RTSP system. Also, near-side bus stops were found to introduce extra transit delays when TSP was on under certain conditions. Therefore, besides regular recommendations to avoid these extra delays, such as moving a near-side bus stop to the far side of the intersection, we recommend that the TSP treatment of extended green may be disabled at intersections with near-side bus stops to avoid introducing negative impacts on transit vehicles.

CHAPTER 1 INTRODUCTION

1.1 Research Background

Transit signal priority (TSP) is an operational strategy that facilitates the movement of in-service transit vehicles through signalized intersections. Since delays incurred by transit vehicles at signalized intersections typically account for 10 to 20 percent of transit vehicle running times, TSP promotes transit utilization through improving service reliability (Baker, 2002). As an important ITS technology, TSP systems use sensors to detect approaching transit vehicles and alter signal timings, if necessary, to prioritize transit vehicles and improve their performance. For example, a green signal can be extended for a late transit vehicle to avoid further delay at the intersection. By reducing waiting time of transit vehicles at intersections, TSP can reduce transit delay and travel time, thereby increase transit quality of service. Implementation of TSP gives transit customers a more dependable service through greater schedule adherence and a more comfortable ride due to decreased number of stops and braking at signalized intersections. Transit riders who have experienced smoother and more comfortable rides are more likely to continue using transit services.

The objectives for a transit agency to employ TSP system are twofold: improve service and decrease costs (Garrow and Machemehl, 1997). Through customer service enhancements, the transit agency could ultimately attract more customers. Fewer stops also mean reductions in drivers' workload, fuel consumption, vehicle emissions, and maintenance costs. Greater fuel economy and reduced maintenance costs can result in increased efficiency of transit operations. TSP can also help reduce transit operation costs, as reductions in transit vehicle travel times may allow a given level of service to be offered with fewer vehicles. Reductions in bus running time and number of stops may also lower vehicle wear and tear, and consequently lead to deferred vehicle maintenance and new vehicle purchases (Garrow and Machemehl, 1997). Local transportation agencies can benefit from TSP strategies as well when more auto users decide to switch to public transportation as a result of improved transit service. Reduced demand on personal car travel will finally help improve roadway service level.

Due to the rapid growth of population and economy in the Greater Seattle Area, traffic congestion has become an increasingly important issue. Improving transit services to reduce personal car travel demand are considered an effective countermeasure against traffic congestion. The South Snohomish Regional Transit System Priority (SS-RTSP) system, therefore, was launched to improve the level of services for Community Transit (CT) buses.

1.2 Problem Statement

In the past two decades, TSP systems have been deployed in many cities worldwide. However, enthusiasm for TSP in North America has been tempered with concerns that overall traffic performance may be unduly compromised when signal timing plans intended to optimize traffic flow are overridden to provide a travel advantage to transit vehicles (Chang and Ziliaskopoulos, 2002). To quantitatively evaluate the effect of TSP, several studies (see, for example, Abdulhai et al., 2002, and Dion et al., 2002) have been conducted in recent years. While these studies generally agree on the benefits for transit operations, the overall impacts of TSP on local traffic networks remain unclear. Also, since performance of a signal control strategy is closely related to traffic conditions, surrounding land use, traffic regulations, and roadway network geometry, comprehensive impacts of TSP systems on transit and other vehicles are case specific and difficult to be generalized. This implies that TSP effects on a particular network need to be evaluated based on field observed data. Therefore, a comprehensive evaluation on the SS-RTSP system is of academic interests and practical significance.

There are two phases of the SS-RTSP system installation and evaluation. Phase one involves four intersections on the SW 164th Street in south Snohomish County. Phase two covers twenty-nine intersections on Highway 99 in the City of Lynnwood. Due to hardware conflicts between the TSP system and Lynnwood's traffic control system, phase two evaluation cannot be conducted as scheduled. Therefore, this report summarizes phase one evaluation only. Results for phase two evaluation will be recorded in a follow-up report.

1.3 Research Objective

In this study, impacts of the phase-one SS-RTSP project on both transit and local traffic operations are quantitatively evaluated based on field-observed data. A series of measure of effectiveness (MOE) are developed to measure the traffic performance. Specifically, there are three major objectives for this research:

- Quantitatively evaluate the TSP system benefits for transit operations;
- Calculate the overall impacts of the TSP system on local traffic networks; and
- Understand how TSP effects change with traffic conditions and signal control strategies.

CHAPTER 2 STATE OF THE ART

Interests in TSP can be dated back to the 1970s. Typical performance measures used for TSP evaluation include changes in transit travel times, intersection delay, average vehicle delay, average vehicle stops, average person delay and average person stops. The work of Ludwick (1975) was among the first TSP studies in the United States. This evaluation was for the initial Urban Traffic Control System - Bus Priority System (UTCS-BPS) in Washington, D.C., and used a microscopic simulation model, UTCS-1. Using the UTCS-1 model, Ludwick simulated a network with unconditional preemption for transit buses, applying the early green or extended green logic.

Sunkari et al. (1995) developed a model to evaluate a bus priority strategy for one signalized intersection in a coordinated signal system. The model used the delay equation employed by the Highway Capacity Manual (2000) for signalized intersections and adapted the equation to calculate person delays for cases with and without priority strategies. Al-Sahili and Taylor (1996) performed an analysis of Washtenaw Avenue in Ann Arbor, MI, in 1996 using the NETSIM microscopic model. The maximum benefit found was that a bus could cut down travel time by 6 percent. The authors suggested that the most suitable TSP plan for each intersection should be integrated and implemented together as a system to maximize the benefit. Garrow and Machemehl (1997) evaluated the 2.5 mile long Guadalupe N. Lamar arterial in Austin, Texas. The main objective of this study was to evaluate performance of different TSP strategies under peak and off-peak traffic conditions as well as different saturation levels for side street approaches (Chada, and Newland, 2002).

Field evaluations reported by Chang et al. (1995) and Collura et al. (2000) indicated that reductions in average intersection delays ranged from 6 to 42 percent, and reductions in average bus travel times were from 0 to 38 percent. Some studies (Yand, 2004) also found that vehicles sharing the same signal phase with transit vehicles also occasionally benefited from signal priority treatments provided to transit vehicles. While a number of deployments produced no significant impacts on general traffic, others yielded stop and delay increases as high as 23 percent (Baker et al., 2002).

The Transit Capacity and Quality of Service Manual (TCQSM, 2003) provides guidance to practitioners seeking to evaluate the impact of a TSP system. The TCQSM recommends using person-delay as the unit of measurement in comparing the benefits and costs of TSP implementation. The person-delay approach assumes that the value of time for a bus passenger is the same as an auto passenger. This assumption allows the benefits and costs of TSP to be evaluated on the same scale and provides flexibility to practitioners in the evaluation by allowing auto occupancy and bus occupancy rates to be variable.

According to the study by Casey (2002), there is an 87 percent increase in the numbers of transit agencies with operational TSP systems from year 1998 (16 agencies) to year 2000 (30 agencies). New and rapid advances in traffic/bus detection and communication technologies, and well-defined priority algorithms have made TSP more appealing or acceptable to more road users of all modes.

CHAPTER 3 PROJECT OVERVIEW

3.1 Major Components

The SS-RTSP project has three major subsystem components, including in-vehicle subsystem, road-side subsystem, and center subsystem. Figure 1 illustrates the SS-RTSP system operation by integrating the three subsystems. When an equipped transit vehicle approaches a TSP-enabled intersection, the in-vehicle device communicates with the road-site antenna. Then the transit vehicle's electronic ID and trip information are read and sent to the traffic signal controller for the transit vehicle's eligibility evaluation. If the transit is qualified to receive TSP and no other TSP has been issued in the current signal control cycle, a TSP treatment may be provided to improve the performance of the transit vehicle (McCain Traffic Supply 2004).

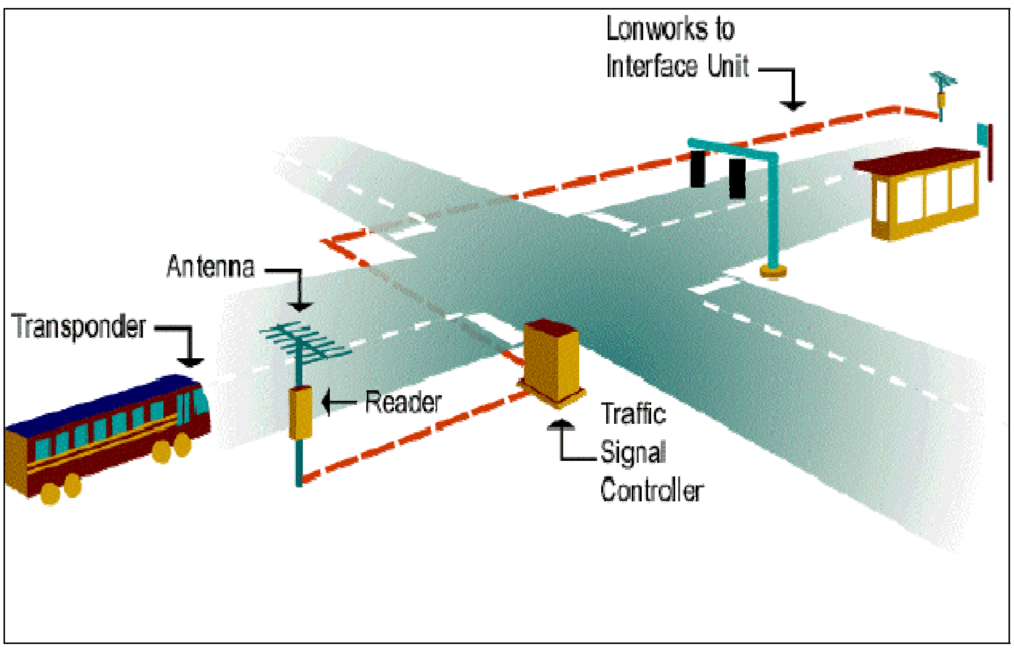

Figure 1 Schematic plan for TSP system operation

The in-vehicle subsystem comprises of mainly a transponder installed on the front site of the transit vehicle. The transponder can provide information of coach number, route number, trip number, and transit system operator ID (such as Community Transit or Metro). The road-side subsystem includes Radio Frequency (RF) antennas mounted in the vicinity of the traffic signals or luminance mast arms, power sources for reader units, and the Transit Priority Request Generator (TPRG). A TPRG contains a microprocessor and a communication device connected with the traffic signal controller. The center subsystem is formed by those devices interfacing with central traffic signal management systems, transit management systems, and home station monitoring systems.

3.2 Priority Strategies

The SS-RTSP system applies active priority strategies. Active priority strategies are dynamic signal timing enhancements, where the signal phases are modified upon the detection of a transit vehicle. These strategies provide efficient operations of traffic signals by responding to transit TSP call and then returning to normal operations after the call has expired or serviced. Although there are several active transit signal priority strategies available, such as phase insert and phase suppression (Baker et al., 2002), only two active transit signal priority strategies are used in the SS-RTSP system:

- Early Green (Early Start or Red Truncation of Priority Phase);
- Extended Green (or Phase Extension of Priority Phase).

Early green and extended green are the most common TSP treatments to transit vehicles. The early green strategy is the process that indicates a green light prior to the normal start of a priority movement phase. This process is implemented by shortening the green time of the conflicting phase(s), without violating the minimum green time and clearance intervals, so that the green time for the priority phase can start early. The extended green strategy holds the green signal for the priority phase for some more seconds in order to facilitate eligible vehicles to pass the intersection without further delay. Depending on the signal control policy, green times for conflicting phases may or may not be shortened to compensate the extended green for the priority phase. Both strategies are intended to lower transit vehicle delays at TSP-enabled intersections. Depending upon the arrival time of a TSP-eligible transit vehicle, early green or extended green may be used to provide an appropriate TSP treatment to the transit vehicle.

The priority logic flowchart of the TPRG is shown in Figure 2

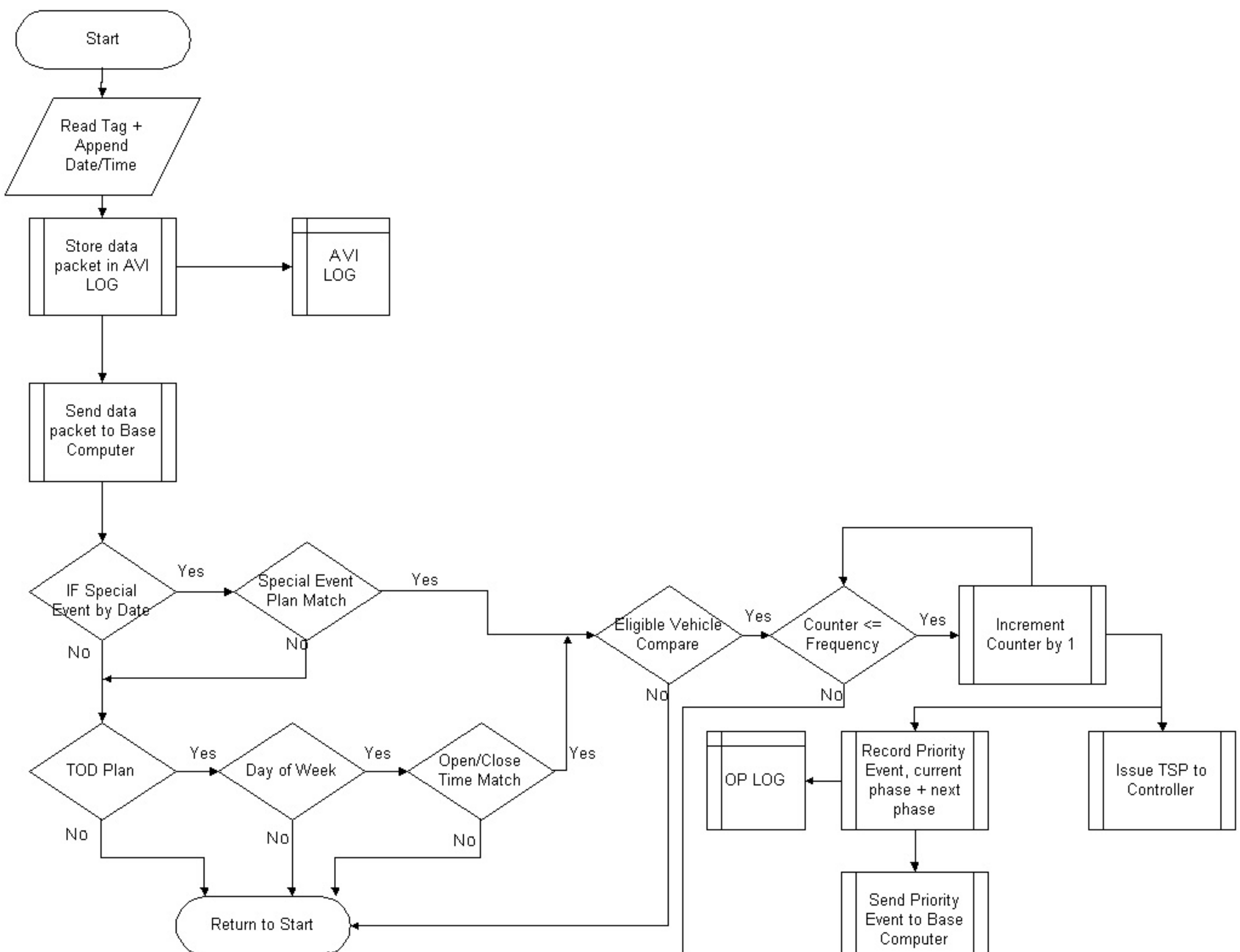

Figure 2 Priority Logic Flowchart

The TPRG will send transit priority request to the traffic controller only for eligible buses when and only when the bus is:

- in operation of one of the three test routes (114, 115 and 116), and
- equipped with Keypad, and
- 0~30 minutes behind its scheduled time.

The Keypad is the device installed beside bus driver's seat to input the data of route number and trip number to the transponder.

CHAPTER 4 METHODOLOGY

4.1 Major Measures of Effectiveness

In order to provide a comprehensive evaluation of TSP strategy impacts, several MOEs have been used to assess impacts on traffic and transit operations regularly. Each of the MOEs reflects the impact of the TSP system from a certain perspective, and they jointly provide a relatively complete assessment on the SS-RTSP project. In this study, we separate the chosen MOEs into two categories: the main MOEs and the secondary MOEs. The main MOEs are those address our major concerns about the SS-RTSP project and can be calculated using field observed data. The secondary MOEs are those useful for in-depth understanding TSP performance but cannot be derived from field observed data. We rely on microscopic simulation models for calculation of secondary MOEs.

The main MOEs chosen for this evaluation study are as follows:

Transit Time Match

TSP systems are designed to help transit vehicles adhere to their schedules. A high on-schedule rate can result in increased ridership and reduced operation costs. In this study, we define the variable of Transit Time Match (TTM) as the difference between actual arrival time and scheduled arrival time at each timing point on the test routes. If the mean of TTM is close to zero, then the transit vehicles adhere to their schedules very well. The actual arrival time is measured with GPS data.

Transit Travel Time

Transit travel time data are collected to evaluate whether the TSP system has caused a significant change in travel time on the test routes. Decreases in transit vehicle travel time can result in a lower operation costs and emission levels. In-vehicle GPS data loggers are used for collecting transit travel time data.

Traffic Queue Length

A major concern with TSP is that TSP treatments that aim at keeping transit vehicles on schedule will cause excessive delay for other intersection movements. Consequently, one of the key evaluation measures will be the size of queue for each conflicting phase and the delays associated with those queues. Before and after analysis on traffic queue length helps answer whether queues get significantly longer for movements not receiving the benefits of TSP treatments because of TSP calls. Also, it helps understand TSP impacts on streets crossing with the TSP corridors. In this study, sample traffic queue length data are collected manually from recorded video images.

Signal Cycle Failures

Signal cycle failures refer to the specific delay condition in which vehicles must sit through at least one complete signal cycle to pass through an intersection. This condition leads to considerable public frustration, and an increase in its occurrence is likely to result in more substantial “public resistance” to TSP than a minor increase in intersection delay. Thus it is a key measure for reporting to public officials. Signal cycle failures are extracted manually from recorded video data.

Frequency of TSP “Calls”

This MOE monitors how frequently (calls per hour) the TSP system actually requests signal priority, and how often those calls result in a “denied” priority request (a priority request may not be granted at a given condition due to the TSP policy). This information will be used along with the intersection delay information to determine if changes to the TSP policy are necessary. If TSP calls are causing further intersection delay, the number of allowable priority calls may need to be reduced. Conversely, if intersection delays are not deteriorating and desirable priority calls are not resulting in changes in signal timing, then additional priority calls should be allowed. Frequency of TSP calls is calculated from the TPRG logged TSP requests from transit vehicles.

In addition to the above primary MOEs, the following secondary MOEs are also very important. Since these MOEs cannot be calculated from field observed data, a microscopic traffic simulation model is built to derive them.

Average Person Delay

This MOE is commonly adopted to reflect the performance of a roadway system. If the average person delay for the whole network is reduced by the SS-RTSP project, then we can conclude a net benefit from the TSP system.

Vehicle Delays and Stops

Average delay per vehicle is the MOE used for intersection level of service evaluation in HCM (2000). In this study, we use averaged vehicle delay and number of vehicle stops to reflect the time loss of vehicles at intersections. Changes of this MOE set before and after the SS-RTSP system indicates the impacts of the TSP system on the performance of the intersections. Additionally, it can also be used for quantifying the impacts of the SS-RTSP system on side streets crossing with the TSP corridors.

4.2 Database Design and Implementation

Since the data collected for analysis are enormous with complicated relationship among them, a well-designed database is needed to store these data and organized them for queries. The database design in this study followed the Entity/Relationship approach. A detailed introduction about this approach is available in Garcia-Molina et al. (2002). Figure 3 shows the Entity/Relationship (E/R) diagram of the database. According to Figure 3, the following database objects are needed:

Entities:

- Bus location
- Bus Assignment Information
- Bus Operation Information
- TSP Calling

Relationships:

- Belong to: binary, many-one
- Related to: binary, many-one

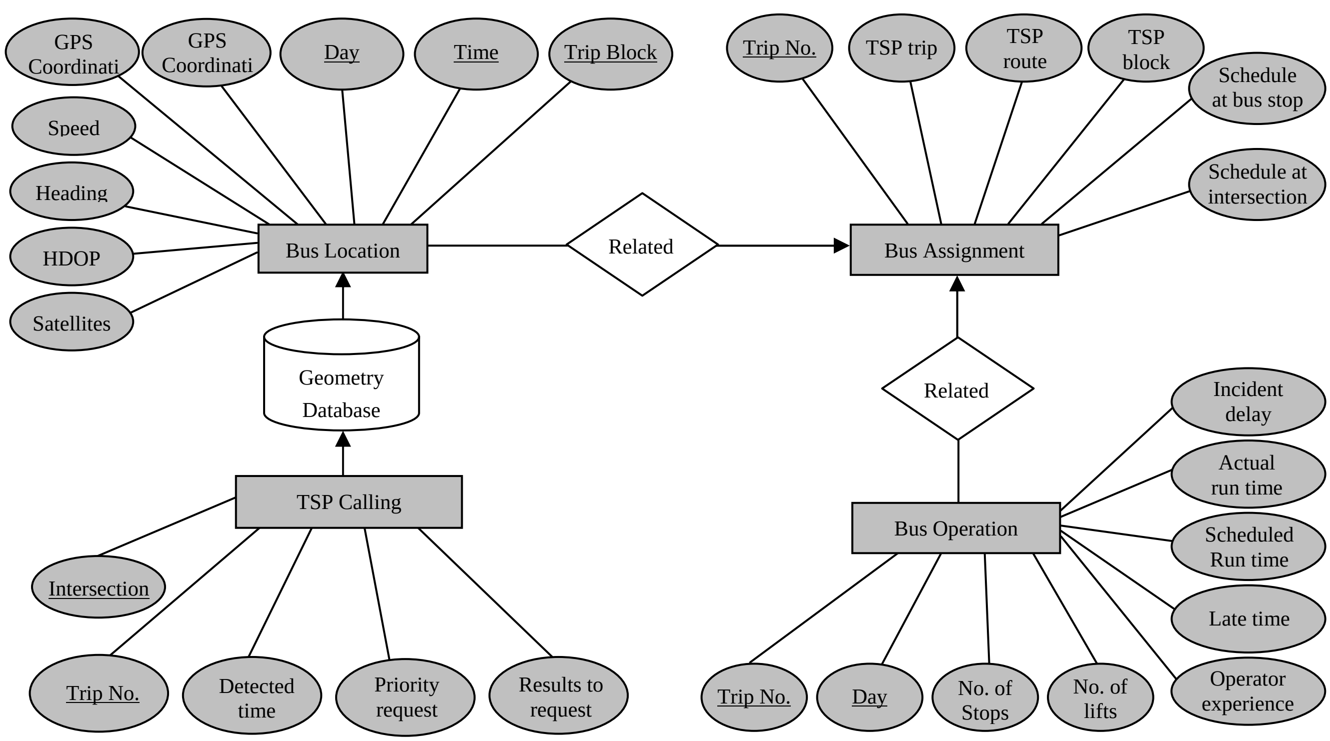

Figure 3 E/R Diagram of Database

Relational schemas:

- Bus location (Trip block, Time (hhmmss), Day (mmddyy), GPS coordination N, GPS coordination W, Speed, Heading, HDOP, Satellites)
- Bus Assignment Information (Trip No., TSP trip, Route No., Trip block, schedule at each time-points on weekday/ Saturday/ Sunday and holiday, schedule at each intersection with TSP sensor on weekday/ Saturday/ Sunday and holiday)
- Bus Operation Information (Trip No., Day, No. of actual stops at bus stops, No. of wheel chair/bicycle lifts, Operator experience (year), late time at the first bus stop (second), scheduled running time (second), actual running time (second), incident delay (second))
- TSP Calls (Intersection ID, Trip No., Bus detected time, Day, Priority request made, Results to request)

Foreign Keys: (Buslocation.Tripblock, Buslocation.Time, Buslocation.Day) references BusAssignmentInformation.TripNo..

Foreign Keys: (BusOperationInformation.TripNo, BusOperationInformation.Day). references BusAssignmentInformation.TripNo..

In this study, we use Microsoft SQL server for data management. This database is, therefore, implemented in the Microsoft SQL Server 2000.

CHAPTER 5 FIELD TEST

Phase one test of the SS-RTSP project covered a period of two weeks, from April 4th to April 17th, 2005. In the first week, the TSP system was turned off, and in the second week it was turned on. TSP was turned on or off on Monday's early morning between 1:00AM and 4:00AM, when there were no CT's transit vehicles in operation. Although TSP is turned off in the first week, we still collected all the data available to conduct a before and after analysis on the SS-RTSP project.

5.1 Corridor

Phase-one test was performed on the 164th Street SW corridor, between the 36th Avenue W and the 25th Avenue W (or NorthPoint). Figure 4 shows the map of test corridor and its location in the Greater Seattle area.

The tested corridor is about 3600 feet long and has four signalized intersections. In the SS-RTSP project, all of the four intersections on the test corridor were equipped with TSP devices. One or two approaches of the four intersections were equipped with TSP readers and can detect transit vehicles with TSP tags. The TSP approaches tested in this project are shown in the following Table.

TABLE 1 TSP Approaches

Intersection	36th Avenue	Park & Ride	Alderwood Mall Parkway	NorthPoint
TSP approaches	Eastbound	Eastbound, Westbound	Westbound	Eastbound, Westbound
TPRG Unit	15010	15000	15020	15030
Reader Unit	15014	15003, 15004	15023	15033, 15034

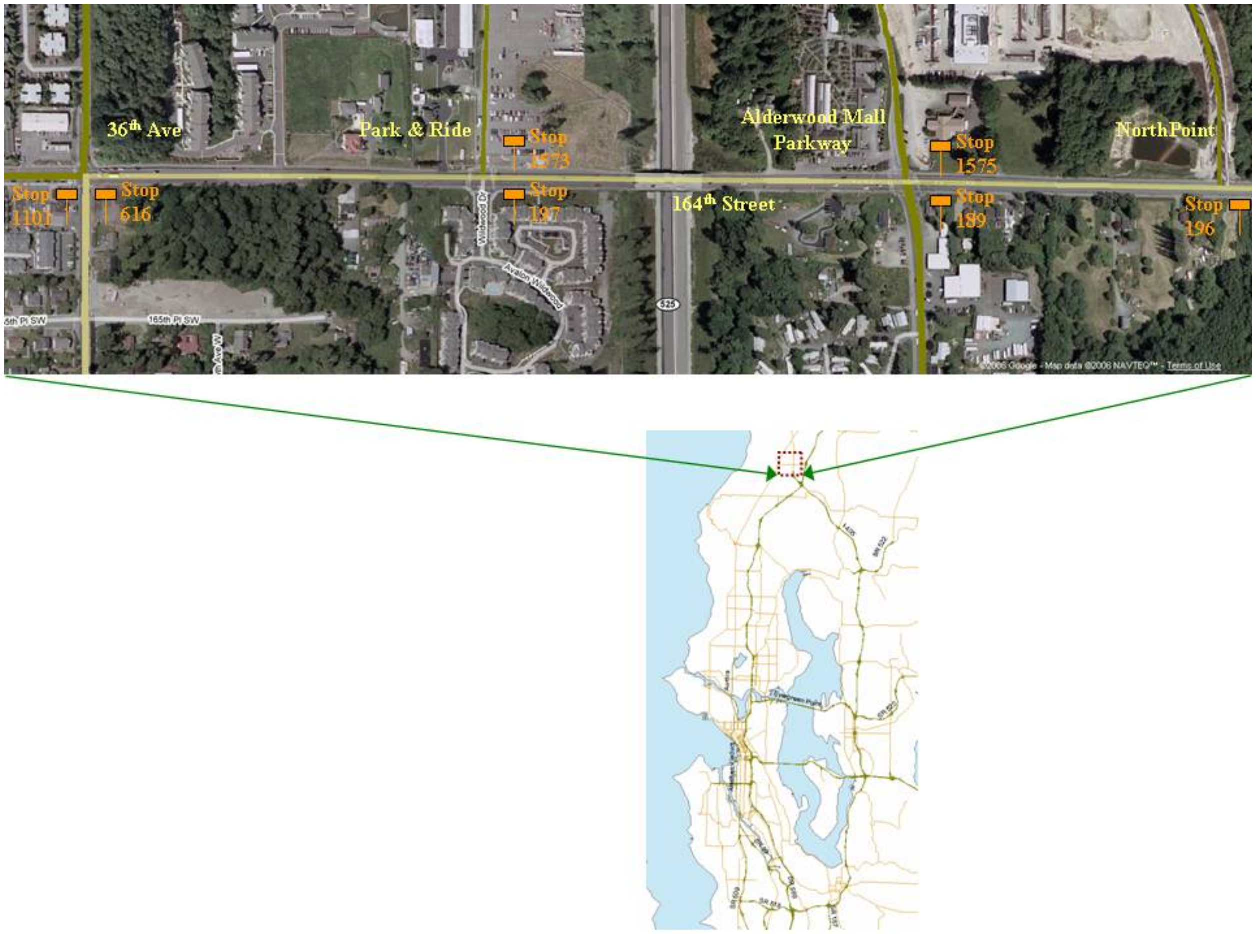

Figure 4 The Test Corridor

5.2 Transit service

The tested transit routes were route 114, 115 and 116 of Community Transit (CT). All the test routes run through the 164th Street between NorthPoint and 36th Ave, and turn on the 36th Ave, as shown in figure 4. There are seven bus stops on this corridor, and three of them are near-side stops: stop 616 (eastbound), stop 1573 and stop 1575 (westbound). Most of the trips on the test routes are performed by coaches equipped with Keypad and eligible for receiving TSP. Table 2 summarizes the number of the eligible TSP trips on the test corridor in one week.

TABLE 2 Number of Eligible TSP Trips on Test Routes

	Per Weekday	Saturday	Sunday	One Week Total
Eastbound	58	25	14	329
Westbound	57	25	14	324
Total	115	50	28	653

5.3 Data source

5.3.1 TSP logs

TSP detection, request, and traffic signal status are recorded in real time by TPRG. A TPRG generates two types of log files: AVI logs and OP logs. Information in AVI logs are actually from the TSP readers about the detected transit vehicle. The following are several example rows in an AVI log file.

06:04:11,15003,1,1,2,7602,0,0,115,2018,21515 ,

06:13:30,15003,1,1,2,5827 ,

06:19:51,15003,1,1,2,9158 ,

Commas are used to separate fields in the log files. The first field shows the time when the coach was detected; the second field is the unit number of the reader; the remaining fields are data transmitted from TSP tags on coaches. Important ones of these fields include coach number, route number, and trip number. The TSP system may also detect and record transit coaches not in the three tested routes but equipped with TSP tags. These vehicles can be easily recognized from the recorded data.

Examples of OP logs are as follows:

06:27:03,15000,Checkout (25),Phase 6 Green to Red: 0

06:27:17,15000,Checkout (25),Phase 6 Red to Green: 0

06:27:38,15000,Checkout (25),Priority Denied - Trip: 9163

06:33:31,15000,Checkout (25),Priority Denied - Phase: 7640

06:29:41,15000,Checkout (25),Priority granted for trip: 21500

06:29:41,15000,Checkout (25),: 7617

The first two fields are the same with the AVI logs. The third field is always the same for all the recorded rows. The fourth field records the change of traffic signal lights in given phases, such as those in the first two rows, or the TPRG treatments to detected buses. A bus's TSP request may be denied for two reasons: "trip" or "phase". "Trip" means the detected bus is not serving TSP-eligible trips of the three test route. "Phase" means the eligible bus is estimated to arrive at the intersection when signal is in green, or the bus is not late. If a bus's TSP request is denied, the reason, together with the bus' coach number, will be logged in the fourth field, as shown in the third and fourth rows in the example. If a bus is given a priority, its trip number will be logged in the fourth field, with its coach number saved in the following row, as shown in the fifth and sixth rows of the example.

5.3.2 GPS data

GPS data were logged by GeoStats In-Vehicle GeoLogger^{TM} installed on transit coaches. GeoLogger can track up to 12 satellites and update data in every second, with position accuracy of 15 meters in root-mean-square (RMS). Totally 13 GeoLoggers were install on test coaches. All these GeoLoggers were pre-set to record data every second when the vehicle speed is higher than 1.15 mile per hour. The following is an example of logged GPS data:

A,47.81633,N,122.29803,W,133813,110405,004.7,317,,05.8,04

The first field shows if the working status of GPS. If the status is ok, the GeoLogger records an "A". The next four fields are the coordinates of vehicle position shown in longitude and latitude. The fifth field shows time in the "hhmmss" format. The sixth field represents date in the "ddmmyy" format. The seventh filed is the speed in miles per hour. The eighth field is the heading of the vehicle in degree. The last two fields are about the satellite signal quality, showing Horizontal Dilution of Precision (HDOP) and number of satellites, respectively. To analyze position data more conveniently, we wrote a piece of MATLAB™ code to transfer the position from the longitude and latitude coordinate system into NAD 1927 State Plane Washington North FIPS 4601.

5.3.3 Traffic controller logs

Traffic control events were periodically recorded by traffic controllers. Depends on the controller type and model, event data such changes of signal control phases and traffic calls may be recorded. Traffic volume can be derived from calls of advance loops (or count loops). Table 3 provides an example of data logged by a traffic controller. A maximum of 32 detectors can be supported at one intersection.

TABLE 3 Example of Traffic Controller Logs

Date Time	Name	Det1	Det2	Det3	Det4	Det5	Det6	Det7	Det8	…
4/14/05 11:30	060 164th SW & Alderwood/Manor	67	35	14	11	52	50	4	24	…

Unfortunately, phase change data of the test intersections were not available for phase-one test of the SS-RTSP project. Through analyzing the traffic light change records provided in the TSP logs, we were able to phase changes during the test period.

5.3.4 Traffic video data

All the four intersections included in this study use Video Image Processors (VIPs) for traffic detection. These detection cameras are typically fixed to cover a designated area for vehicle detection. For recording traffic video, the video channel from a detection camera was split into two channels, one goes to the VIP card and the other goes to our Video Cassette Player (VCR). Twelve VCRs were installed to record traffic images for all the four approaches at both the 36th Ave intersection and the Alderwood Mall Parkway intersection, and the eastbound and westbound approaches at the Park & Ride intersection and the 25th Ave intersection. Six hours video data were collected each day. From Monday through Saturday, the six hour video includes two hours in the morning peak hour (6:30AM~8:30AM), two hours in non-peak hour (12:30PM~2:30PM), and two hours in afternoon peak hour (4:30PM~6:30PM). On Sundays, the six hour video was recorded in two time periods: 6:30AM~8:30AM and 2:30PM~6:30PM.

5.3.5 Other data

Unusual transit vehicle delays may be introduced by incidents, special events, or inclement weather conditions. In order to capture impacts from these factors, we designed a data log form for transit drivers to record reasons for usual delays. Figure 5 shows the data log form. These data can be used to find reasons for usual delays. Since unusual delays may introduce serious errors to TSP evaluation, data associated with unusual delays were removed from analysis.

Date ____________ **Transit Signal Priority Log** Route 114/115/116

Run Number ____________________ Years Driving w/CT ________________

Trip Number	Delay (minute)	Major Reason for the Delay						
		Wheel Chair	Traffic	Weather	Incident	Accident	Reroute	Other
		☐	☐	☐	☐	☐	☐	
		☐	☐	☐	☐	☐	☐	
		☐	☐	☐	☐	☐	☐	
		☐	☐	☐	☐	☐	☐	
		☐	☐	☐	☐	☐	☐	
		☐	☐	☐	☐	☐	☐	
		☐	☐	☐	☐	☐	☐	
		☐	☐	☐	☐	☐	☐	
		☐	☐	☐	☐	☐	☐	
		☐	☐	☐	☐	☐	☐	

Notes: 1. Please only record delays on 164thStreet SW between 36th Ave W and 22nd Ave W.
2. If there are more than one wheel chair operations on the test corridor, please indicate the number of operations beside the check box. If the delay reason is not listed, please indicate it in the "other" column.

Figure 5 Log Form for Bus Drivers

Additionally, bus schedule data were provided by CT. CT also provided trip assignment records, which listed trip numbers assigned to each coach every day during the test period.

All the discussed data, except for the traffic video data, were stored in the designed database. Structured Query Language (SQL) was used to query and analyze the data.

CHAPTER 6 SIMULATION ANALYSIS

6.1 Simulation Tool

Average person delays, vehicle delays, and stops are several important performance measures for the system evaluation. As mentioned earlier, these MOEs are not directly calculable from the field observed data; hence, simulation models were established to computing them in this study. Traffic simulation software VISSIM version 4.10 was exploited to emulate traffic operations with or without the functions of the TSP system. VISSIM is a microscopic behavior-based simulation tool that can model integrated roadway networks and various modes including general purpose traffic, buses, High Occupancy Vehicles (HOV), light rail, trucks, bicyclists and pedestrians. VISSIM can also implement some advanced traffic systems and control strategies such as TSP systems, provide effective measures to assess their benefits and costs, and then further optimize system operations (VISSIM User's Manual, 2004).

6.2 Simulation Model

The section of 164th Street SW between the 36th Avenue W and the 25th Avenue W (or NorthPoint) in the City of Lynnwood was modeled to simulate the corresponding practical test sites. The simulation model was configured by actual layout of the corridor and traffic control parameters. Field observed traffic volumes, transit ridership estimates, and vehicle occupancy data were used to calibrate the model. Details of model set up and calibration are described as follows.

6.2.1 Modeling the 164th Street SW

To model the phase-one test corridor, arterial geometric characteristics and transit stop coordinates were obtained from construction designs and the computer-aided map tools such as the software ArcGIS9.0 and GPS systems besides practical observations (Snohomish County, 2003). Traffic control and operational parameters at the test corridor were collected from the Snohomish County Department of Transportation.

In accordance with the practical test situation, the TSP function was enabled in the control strategies for four intersections, including 164th St & 36th AVE, 164th St & Park and Ride, 164th St & Alderwood Mall Parkway, and 164th St & NorthPoint. The emulated NEMA controller in VISSIM can be properly configured as a standard NEMA controller to satisfy requirements of fully actuated signal control and basic TSP operations. Thus, in this study the emulated NEMA controllers were applied in the simulation model to implement the real signal control plans in operation for each intersection. A basic TSP routine is supported by NEMA controller. A transit call detected by sensors may generate a request for early green or extended green operation that is consistent with the SS-RTSP system.

6.2.2 Simulation model calibration

Traffic volumes for the approaches were set on the basis of actual volumes observed by traffic sensors. Some traffic volume data were double-checked by ground-truth video tapes recorded at the test intersections. Traffic flows of intersection approaches generated by the simulation program reasonably distributed in the range from 50 vehicle-per-hour-per-lane (vphpl) to 1250 vphpl and matched field observed volumes very well.

The passenger ridership on buses was estimated based on annual ridership of CT (National Transit Database, 2004). In our model the ridership was selected as 12 passengers per vehicle (ppv). The average vehicle occupancy for general purpose vehicles was estimated to be 1.2 occupants per vehicle, as determined by King County Metro based on their field observations (King County Department of Transportation, 2002). Additionally, the generation rate of passengers is set as 10 persons per hour (pph) based on the number of boardings at each stop (Community Transit, 2005). Other parameters, such as bus headways, bus stops' locations and so on, were calibrated according to the real values. Figure 6 shows a snapshot of the simulation model for the intersection of 164th St & 36th AVE.

Figure 6 A Snapshot of the simulation model

Traffic control settings of the simulation model were also calibrated by actual traffic operation parameters and control plans. Internal parameters for the simulation model were properly adjusted ensure the model's appropriateness to the corresponding application. After the simulation model was properly calibrated, six-hour simulation test was conducted: three hours for TSP-on and the other three hours for TSP-off.

CHAPTER 7 RESULTS AND DISCUSSION

7.1 Statistics for Granted TSP Trips

Table 4 shows the number of granted TSP trips based on the TSP log files. When a TSP-eligible trip was granted for priority treatment, a priority requests was sent to traffic controller by TPRG. Then the traffic controller issues proper TSP treatment to the bus. The percentage data in Table 4 shows the share of granted trips in all the TSP-eligible trips. We can see that the sample size of granted TSP trips was different from day to day and from intersection to intersection. Considering that traffic flow condition varies from time to time, it is desirable to have higher numbers of granted TSP trips at the intersections than those shown in Table 4. However, given the relatively low service frequency of CT buses at the test corridor, this is the best set of data we can get and use for this evaluation study.

TABLE 4 Number of Granted TSP Trips

Date	Number of Granted TSP Trips									
	15010		15000		15020		15030		Total	
2005/04/11	19	43.2%	25	27.5%	26	55.3%	43	47.3%	113	41.4%
2005/04/12	1	6.3%	0	0.0%	4	25.0%	5	15.6%	10	10.4%
2005/04/13	5	14.3%	20	28.2%	20	55.6%	25	35.2%	70	32.9%
2005/04/14	16	43.2%	29	38.2%	24	61.5%	32	42.1%	101	44.3%
2005/04/15	13	37.1%	34	47.9%	26	72.2%	48	67.6%	121	56.8%
2005/04/16	2	11.8%	5	13.5%	11	57.9%	19	51.4%	37	34.3%
2005/04/17	0	0.0%	4	22.2%	8	88.9%	11	61.1%	23	42.6%
Total	56	29.0%	117	29.5%	119	58.9%	183	46.2%	475	40.1%

7.2 Benefits

7.2.1 Transit Time Match

As defined in Chapter 4, transit time match refers to the difference between the actual arrival time at the timing point and the scheduled arrival time in minutes. In this test, because the corridor was relatively short, there were not many timing points for analysis. Therefore, we regarded all bus stops on the corridor as timing points and analyzed transit time match at each bus stop. There were seven bus stops on the test corridor, and six of them are affected by the TSP system. Transit time match results at these bus stops are shown in Table 5. Transit vehicles' actual arrival times were calculated based on TSP reader logs. The first three bus stops are on eastbound, and the others are on westbound.

TABLE 5 Time Match at Bus Stops

	Stop 197	Stop 189	Stop 196	Stop 1101	Stop 1573	Stop 1575
TSP off	10.2	7.6	7.9	9.7	12.4	10.2
TSP on	8.1	7.3	6.6	9.3	9.0	9.2

The transit time match results showed that when TSP was on, transit coaches were more reliable at each bus stop. The increase of on-time performance varied from 0.3 to 3.4 minutes, or 3.9 percent ~ 27.4 percent, compared to the scenario when TSP was off.

7.2.2 Transit Travel Time

Transit travel time data were calculated using GPS position data. Table 6 shows the descriptive statistics for transit travel time across the test corridor. The east end of the corridor is defined as the point on the center line of 164th Street nearest to TSP reader 15034; the west end is on the center line of 36th Ave and the stop bar of south approach.

TABLE 6 Transit Corridor Travel Time

		Eligible Trips with TSP off	Eligible Trips with TSP on	TSP Granted Trips
Mean travel time (sec)	Westbound	142.9	144.4	146.7
	Eastbound	135.2	131.6	128.4
Standard deviation (sec)	Westbound	29.2	30.3	28.9
	Eastbound	32.6	32.8	30.4
Maximum (sec)	Westbound	210.0	233.0	233.0
	Eastbound	269.0	287.0	205.0
Minimum (sec)	Westbound	95.0	87.0	90.0
	Eastbound	85.0	79.0	82.0

Compared with the mean travel time of eligible trips with TSP off, the average travel time for the eastbound of granted trips was 6.8 seconds shorter when TSP was on, which was 5.0 percent of the average eastbound travel time of eligible trips with TSP off. The standard deviation of eastbound travel time was also lower for trips with granted signal priorities, which means the travel time was more predictable when TSP was on.

For the westbound, the mean travel time was longer when the TSP was on, and even longer for the trips with granted priorities. This seemed controversial to our expectation. However, if we look at the locations of the westbound bus stops, the results are acceptable. Of the three bus stops on the westbound corridor, two are near-side bus stops. Near-side bus stops may have negative impacts on trips with granted priority. Section 7.3.2 provides a detailed analysis on impacts of near-side bus stops on TSP. Although there is also a near-side bus stop on the eastbound, the bus stop was located at a corner of the intersection where transit vehicles turn right. Considering that right-turn movements may be conducted even on red signal, the negative impact from this near-side bus stop on travel time was not as noticeable as the westbound ones. Therefore, the westbound average travel time of TSP-granted trips exceeded the mean travel time when the TSP system was off, but the eastbound mean travel time did not.

Table 7 shows the mean and standard deviation of transit travel time at intersections. The starting and ending points for intersection travel time calculation were defined as the points 200 ft upstream and 200 ft downstream from the intersection's center point, respectively. However, for intersections with a near-side bus stop, the starting point for the corresponding direction was re-defined as the mid point of the bus stop and the stop bar.

TABLE 7 Transit Intersection Travel Times

			Eligible Trips with TSP off	Eligible Trips with TSP on	Granted Trips with TSP on
Travel time (sec)	36 Ave	Westbound	57.60	24.89	21.59
		Eastbound	21.18	18.41	19.43
	Park & Ride	Westbound	16.90	16.48	16.77
		Eastbound	10.56	12.38	12.10
	Alderwood Mall Parkway	Westbound	40.75	17.56	18.18
		Eastbound	22.20	16.03	18.18
	NorthPoint	Westbound	9.88	8.91	8.97
		Eastbound	9.00	8.81	9.11
Standard Deviation (sec)	36 Ave	Westbound	61.83	12.22	10.36
		Eastbound	15.68	8.38	8.90
	Park & Ride	Westbound	6.47	7.68	8.70
		Eastbound	1.74	5.30	4.43
	Alderwood Mall Parkway	Westbound	19.14	14.22	15.96
		Eastbound	14.55	13.12	15.39
	NorthPoint	Westbound	0.64	0.88	0.94
		Eastbound	1.41	1.12	1.25

In general, the SS-RTSP system decreased transit vehicles' intersection travel time. The only exception is the eastbound direction for the intersection of Park & Ride, where the mean travel time of TSP-eligible trips was 1.82 seconds higher with TSP-on than that with TSP-off. This may be because of the exceptionally good traffic condition at this location in the TSP-off week when the data was collected. This inference was based on the small standard deviation of 1.74 seconds compared to that of 5.30 seconds when TSP was on. The transit travel time savings from the SS-RTSP system varied from intersection to intersection: at the intersections with 36th Ave and Alderwood Mall Parkway, the savings were significant for the westbound travels. At other place, the savings were in one or two second range.

For most of the intersections, the standard deviation of intersection travel time was also decreased when TSP was on. Smaller travel time deviation indicates more reliable transit trips. Readers may have noticed that, in many cases, the mean travel times for TSP-granted trips were higher than those for all TSP-eligible trips. This is probably due to the fact that TSP-granted trips are normally tough trips occurring in congested traffic condition. Therefore, it is very likely that TSP-granted trips experience a longer travel time than all TSP eligible trips.

7.2.3 Average Person delay

Based on the simulation model described in Chapter 6, average person delay was calculated from the simulation results. Delays for passengers in both transit vehicles and general purpose vehicles were included in the calculation. Table 8 shows calculated average delays per person at the test intersections for both the TSP-on and TSP-off conditions.

TABLE 8 Simulation Results for Personal Delays

		36^{th} Ave	Park & Ride	Alderwood Mall Parkway	NorthPoint	Total
TSP off	Personal Delay	16.9	3.0	10.3	2.0	8.7
	Number of Passengers	8271	6574	7854	6188	28887
TSP on	Personal Delay	16.7	2.9	10.1	2.0	8.6
	Number of Passengers	8252	6561	7858	6186	28857

As we can see in Table 8, the average person delay was reduced by the SS-RTSP system. Over all the four intersections, the TSP system saved an average of 0.1 second for all passengers. Although the 0.1 second time saving seems marginal to each person, the overall benefit of more than 48 person-hours over a three-hour period (peak hours) is significant. This indicates a total peak-hour time saving of 96 person-hours (here we assume six peak hours per day) or 25,056 person-hours per year. This benefit was achieved through only 18 bus runs over the three-hour period. During the same time period, there were 5000 regular vehicles generated. Considering sample sizes for different vehicle categories we can reach a conclusion that the average person delay decreased by the SS-RTSP system is noticeable.

7.3 Costs

7.3.1 Vehicle delays and stops

The control delay per vehicle is the only criteria representing the Level of Service (LOS) of signalized intersections (Transportation Research Board, 2000). Vehicle delays at major cross streets were manually collected from traffic video images. Table 9 shows the average vehicle delays calculated from the manually collected vehicle delay data for April 4 and 11, 2006.

TABLE 9 Vehicle Delays

	Intersection	time period	Approach	Intersection Delay (Second)
TSP off	Alderwood	7:30am - 8:00am	North approach	25.09
	Alderwood	2:00pm - 2:30pm	North approach	41.84
	Alderwood	4:30pm - 5:00pm	North approach	42.50
	Alderwood	7:30am - 8:00am	South approach	26.47
	Alderwood	2:00pm - 2:30pm	South approach	37.30
	Alderwood	4:30pm - 5:00pm	South approach	35.94
	36th Ave.	7:30am - 8:00am	West approach	17.72
	36th Ave.	2:00pm - 2:30pm	West approach	18.12
	36th Ave.	4:30pm - 5:00pm	West approach	25.03
TSP on	Alderwood	7:30am - 8:00am	North approach	30.22
	Alderwood	2:00pm - 2:30pm	North approach	27.76
	Alderwood	4:30pm - 5:00pm	North approach	42.64
	Alderwood	7:30am - 8:00am	South approach	25.54
	Alderwood	2:00pm - 2:30pm	South approach	20.77
	Alderwood	4:30pm - 5:00pm	South approach	31.96
	36th Ave.	7:30am - 8:00am	West approach	11.83
	36th Ave.	2:00pm - 2:30pm	West approach	17.55
	36th Ave.	4:30pm - 5:00pm	West approach	23.96

A paired t-test was performed to compare the vehicle delays before and after the SS-RTSP implementation. The t ratio was 1.799, which is smaller than the critical t ratio of 1.860 at p=0.05 level. Therefore, the change of control delay for vehicles on major cross streets was not significant after the SS-RTSP implementation.

The intersection control delays and number of vehicle stops for all approaches were also collected from the simulation experiments. Table 10 shows the average control delay and number of stops at each intersection.

For three out of the four intersections, average intersection control delay and number of stops were decreased by the SS-RTSP system. This result implies that although TSP takes over green time from other phases to serve transit vehicles, the overall effect was positive for most intersections on the test corridor. The only exception was the intersection with NorthPoint where both average control delay and number of stops increased slightly after the SS-RTSP implementation. Since this intersection is less busy than other three intersections, the negative impacts from the SS-RTSP system at this intersection were not enough to offset the positive impacts at other intersections. Therefore, the SS-RTSP project demonstrated a net positive impact on intersection control delays and number of vehicle stops.

TABLE 10 Simulation Results for Average Vehicle delays and Stops

		36^{th} Ave	Park & Ride	Alderwood Mall Parkway	NorthPoint	Total
TSP off	Control Delay	16.5	2.7	10.3	1.6	8.5
	Number of Stops	0.61	0.10	0.40	0.11	0.33
	Number of Vehicles	6728	5323	6399	4994	23444
TSP on	Control Delay	16.4	2.6	10.0	1.7	8.4
	Number of Stops	0.60	0.09	0.39	0.12	0.33
	Number of Vehicles	6725	5324	6400	4993	23442

7.3.2 Traffic Queue Length

The traffic queue length in vehicles was manually counted from field recorded video data. Table 11 shows the traffic queue length on cross streets. Due to time constraints, only Mondays' data were analyzed and summarized in Table 11.

TABLE 11 Traffic Queue Length On Cross Streets

	Intersection	Cross Street	Average Queue Length Per Cycle	Standard Deviation	Maximum	Median
TSP off	Alderwood Mall Parkway	South approach	2.65471	2.41476	14	2
	Alderwood Mall Parkway	North approach	1.56651	1.31575	7	1
	36Ave	West approach	3.20079	2.58121	16	3
TSP on	Alderwood Mall Parkway	South approach	2.64318	2.43128	12	2
	Alderwood Mall Parkway	North approach	1.63679	1.40252	7	1
	36Ave	West approach	3.27135	2.76868	16	3

Paired t-test was performed to compare the average queue length before and after TSP implementation. The *t* ratio was -1.578, the absolute value of which is smaller than the critical *t* ratio of 2.920 at p=0.05. Therefore, the change of the average queue length on cross streets after the SS-RTSP implementation was not significant. The average traffic queue length slightly increased for about 0.07 vehicles per signal cycle when TSP system was turned on. However, on the southbound of the Alderwood Mall Parkway intersection, traffic queue length decreased for about 0.01 vehicles per cycle. This may be caused by regular traffic variations between the two study days. Standard deviations of queue length also increased a little for all the three cross streets when TSP was on. Maximum queue length stayed at almost the same level after the TSP implementation. On the southbound of the Alderwood Mall Parkway intersection, maximum queue length even decreased for two vehicles per cycle when the TSP system was on. The median value of traffic queue length was exactly the same before and after the implementation of the TSP system.

7.3.3 Signal Cycle Failure

Signal cycle failure (or overflow) is an interrupted traffic condition in which a number of queued vehicles are unable to depart due to insufficient capacity during a signal cycle. From a motorist's point of view, cycle failure can be more easily perceived than average control delay or queue length. Signal cycle failure data were also manually collected from traffic video images. Table 12 shows the frequency of signal cycle failure at cross streets on Mondays of the two study weeks.

TABLE 12 Signal Cycle Failure

	Intersection	Cross Street	Signal Cycle Failure per Cycle	Standard Deviation	Maximum Number of Vehicles in a Failure
TSP off	Alderwood Mall Parkway	South approach	0.01121	0.12492	2
	Alderwood Mall Parkway	North approach	0.00229	0.04789	1
	36Ave	West approach	0.00000	0.00000	0
TSP on	Alderwood Mall Parkway	South approach	0.00909	0.19069	4
	Alderwood Mall Parkway	North approach	0.00000	0.00000	0
	36Ave	West approach	0.00413	0.11134	3

Again, we use paired t-test to compare the average frequency of signal cycle failures before and after TSP implementation. The *t* ratio is 0.044, which is much smaller than the critical value of 2.920 at p=0.05. Therefore, the change of the average number of signal cycle failures after TSP implementation was not significant at p=0.05 level. The frequency of signal cycle failure may slightly increase or decrease depending on flow and signal control conditions after

TSP was turned on. When TSP was on, the standard deviation of signal cycle failure may also increase or decrease in a narrow range. The maximum number of vehicles caught in one cycle failure may also increase or decrease after TSP was turned on. This is consistent with the maximum queue length analysis described in Section 7.3.2.

7.4 Discussion on Possible Improvements for the SS-RTSP System

7.4.1 Frequency of TSP calls

As shown in Table 4 in Section 7.1, the distribution of TSP-granted trips during the week as well as across the corridor was not even. In average, the number of TSP-granted trips per day per intersection was about 16.96. This is a relatively low value and the benefits from TSP could be limited because of the low TSP-granted trips. The low number of TSP-granted trips does not necessarily reflect good traffic conditions. Actually, not all transit vehicles of the three test routes had Keypad installed when the test was conducted. Without a Keypad, a transit vehicle is not able to take advantage of the SS-RTSP system. More Key-pad can be installed on these coaches to enable them to receive TSP when necessary. On the phase-one test corridor, there are only three transit routes eligible for TSP treatment, and more transit routes can be added into the TSP system.

7.4.2 Near-side bus stops

Many researches found that at intersections with a near-side bus stop and the transit detector upstream of the bus stop, the benefits from TSP decreases significantly (Baker et al 2002, Ngan 2003, and Rakha and Zhang, 2004). The reason is that the existence of the near-side bus stop makes it very difficult to accurately predict the travel time from the upstream transit vehicle detector to the stop bar. In addition to vehicle speed and the distance from the transit vehicle detector to the stop bar, there are several other factors, such as the numbers of passengers to load and to unload, impact the travel time. These factors are typically random and are not known when a TSP treatment decision is made. TSP treatments based on wrong travel-time predictions will not only waste the valuable green time, but also decrease the expected transit benefits from TSP. Furthermore, extra delays to transit vehicles may be introduced by TSP treatments, compared with non-TSP, under certain conditions.

In this study, we proved that near-side bus stop increases transit delays under certain conditions at TSP-enabled intersections, which seems against our intuition. To evaluate impacts of near-side bus stops on transit delay at intersections, a theoretical model was developed by Zheng et al. (2006). The conditions studied in this research includes: an upstream check-in transit vehicle detector, two TSP treatments of green extension and red truncation, a fixed-time and un-coordinated traffic signal plan. The methodology was to compare bus movements with TSP on and off in time-space diagrams. When a transit vehicle arrives at the stop line of a TSP-enabled intersection, there are four possible scenarios: 1) the transit vehicle received a green extension and benefited from the treatment because it skipped the near-side bus stop; 2) the transit vehicle received a green extension but missed the treatment because of the dwell at the near-side bus stop; 3) the transit vehicle received a red truncation and skipped the near-side bus stop; 4) the transit vehicle received a red truncation and made a stop at the near-side bus stop. Transit delays were analyzed for all the four scenarios. Except scenario two, all the other scenarios benefit from the TSP treatments. However, the expected delay may still be a net increase because the cost for missing green extension is high. Most of our theoretical results were backed up with simulation data. With this model, the extra cost from the near-side bus stop can be calculated. For details of the model, please refer to Zheng et al (2006).

Based on the research results, recommendation can be given to improve the performance of the TSP system. Since scenario two is the only source of extra transit delays, green extension may not be a worthy treatment and can be disabled at intersections with near-side bus stops. The near-side bus stop can also be moved to the far side of the intersection if necessary.

CHAPTER 8 CONCLUSIONS AND RECOMMENDATIONS

8.1 Conclusions

In this study, the SS-RTSP system (phase one) was evaluated with field-observed data. A simulation model was also built and calibrated to compute MOEs that cannot be obtained from field-observed data. With the simulation model and field observed data, the impacts of the SS-RTSP system on both transit and local traffic operations were quantitatively evaluated.

Our evaluation results showed that the SS-RTSP system introduced noticeable benefits to transit vehicles, with insignificant negative impacts to local traffic on cross streets. The overall impact of the SS-RTSP system on local traffic of the whole intersection was net benefit.

With the SS-RTSP system, transit vehicles can be operated more reliably. The MOE of Transit Time Match indicated improvements ranging from 0.3 to 3.4 minutes, or 3.9 percent ~ 27.4 percent at the tested transit stops. The mean eastbound corridor travel time of transit vehicles was 6.7 seconds or 4.9 percent shorter for granted trips than the average corridor travel time without TSP. The average intersection travel time of transit vehicles for granted trips at all the four intersections (including both eastbound and westbound directions) was 6.11 seconds or 29.14 percent shorter compared with intersection travel time with TSP off. Because of the saved transit travel time, the SS-RTSP system decreased the overall personal delays. The results showed that the average person delay was reduced by 0.1 second for all the passengers who used the intersections.

The SS-RTSP system increased cost of local traffic on cross streets. The test results showed slight change in vehicle delay, queue length, and signal cycle failure frequency on cross streets. However, the t tests indicated that these changes were not significant after the TSP implementation.

Similarly, the SS-RTSP system introduced slightly longer delays to local traffic on cross streets. However, our evaluation results showed that benefit received by local traffic sharing the same phase with the transit vehicles was more than offsetting the cost of cross street traffic. Consequently, the whole intersection got benefits from the TSP system. The average vehicle delay of all movements of the tested intersections decreased 0.1 second after TSP implementation.

However, phase-one evaluation of the SS-RTSP system was based on a limited amount of data and on a relatively short corridor. Conclusions obtained from this evaluation study may not be applicable to more general conditions of TSP systems.

8.2 Recommendations

To improve the performance of the current SS-RTSP system, more transit vehicles can be enabled for TSP eligibility. The average number of granted TSP trips was only 16.96 per day per intersection during the test. Considering that the negative impact of the SS-RTSP on local traffic was not significant, more transit trips can be granted with TSP treatment to generate more benefits from the SS-RTSP system.

This research found that extra transit delays may be introduced by TSP, compared with non-TSP, at an intersection with a near-side bus stop under certain conditions. Besides regular recommendations to avoid these extra delays, such as moving a near-side bus stop to the far side of the intersection, our research also suggest that extended green may not be a worthy treatment in this case and therefore can be disabled at intersections with near-side bus stops.

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