Improving Transportation

Mobility, Safety, and Efficiency:

Guidelines for Planning and Deploying

Traffic Signal Priority Strategies

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Final Report

May 25, 2007

1. Report No.
2007-5

2. Government Accession No.

3. Recipient's Catalog No.

4. Title and Subtitle
Improving Transportation Mobility, Safety, and Efficiency: Guidelines for Planning and Deploying Traffic Signal Priority Strategies

5. Report Date
July 2008

6. Performing Organization Code

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8. Performing Organization Report No.

9. Performing Organization Name and Address
University of Massachusetts
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214 Marston Hall
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10. Work Unit No.

11. Contract or Grant No.
VTAOT05-04
0984394:Mob'ty,Sfty

12. Sponsoring Agency Name and Address
VTrans
One National Life Drive
Montpelier, VT 05633

13. Type of Report and Period Covered
Final

14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract
The primary goal of this project is to assist the Vermont Agency on Transportation (VAOT), regional agencies, and local jurisdictions in the State in considering the use of traffic signal systems and technologies to implement traffic signal priority strategies for buses. The study includes an evaluation of the impacts, merits and limitations associated with alternative traffic signal priority strategies and a review of the lessons learned in communities similar to those in Vermont where such strategies have been deployed. An underlying aim of the project is to assist VAOT and other public agencies in the State in planning and deploying signal priority strategies for transit buses in concert with other preferential signal treatments such as traffic signal preemption strategies currently in place and being planned for fire and rescue services. The coordination of traffic signal priority and preemption strategies for multiple types of vehicles is of utmost importance to preserve safety, facilitate emergency response, enhance traffic flow, and improve overall mobility.

17. Key Words
Traffic Signal Priority, Mobility

18. Distribution Statement

19. Security Classification (of this report)
Unclassified

20. Security Classification (of this page)
Unclassified

21. No. Pages
57

22. Price

Abstract

The primary goal of this project is to assist the Vermont Agency on Transportation (VAOT), regional agencies, and local jurisdictions in the State in considering the use of traffic signal systems and technologies to implement traffic signal priority strategies for buses. The study includes an evaluation of the impacts, merits and limitations associated with alternative traffic signal priority strategies and a review of the lessons learned in communities similar to those in Vermont where such strategies have been deployed. An underlying aim of the project is to assist VAOT and other public agencies in the State in planning and deploying signal priority strategies for transit buses in concert with other preferential signal treatments such as traffic signal preemption strategies currently in place and being planned for fire and rescue services. The coordination of traffic signal priority and preemption strategies for multiple types of vehicles is of utmost importance to preserve safety, facilitate emergency response, enhance traffic flow, and improve overall mobility.

Major conclusions of this study are:

- Results of transit priority system deployments in the U.S. and abroad reviewed in Task 1 suggest that transit priority in small, medium, and large urban areas may reduce transit travel time and may lead to improvements in transit schedule adherence and other aspects of transit performance without major negative impacts on overall traffic flow.
- Migrating to a single transit signal priority and emergency preemption system as a long range plan is an admirable goal on the part of officials in the Chittenden County Region and to operate with the two existing systems in an “unencoded” manner is a reasonable step to take unless abuse by unauthorized users takes place or other problems arise.
- The results of the preliminary simulation analyses conducted in Task 2 suggest that transit priority may aid in improving overall bus travel time along Route 15 and the Old North Loop and that these results are generally consistent with the results reported in other transit signal

priority simulation analyses as well as before and after field studies as reported in the literature review in Task 1. In addition, the simulation analyses suggest that there is no significant evidence that the ten second green extension increases delay for the non-transit traffic along the streets intersecting Route 15 and the overall traffic on the Old North Loop.

- The guidelines developed as part of Task 4 should be considered by VAOT, local jurisdictions, transportation agencies, and public safety agencies in the planning and design of transit priority strategies and treatments along signalized arterials in the State.

Recommendations for future research:

- Carry out additional simulation analyses considering other priority strategies including longer green extensions and multiple AM, PM, and mid-day peak analysis periods. As part of future simulation analyses, sensitivity analyses should be included considering different bus headways, bus stop types and locations, and fare collection methods.
- Conduct a small scale transit priority field test in conjunction with the additional simulation analyses. As part of the field test, a set of transit priority objectives and evaluation criteria should be used to assess the performance of the priority system. These objectives and criteria should relate to bus service reliability, bus efficiency, and other impacts on non-transit traffic and overall traffic flow as presented in Task 3.
- As part of a transit priority field test it is recommended that a contractor (e.g. the system/equipment vendor or a third party) be responsible for quality control throughout the system installation process. Consideration should be given where appropriate to the preparation of roadside equipment installation drawings especially when excavation in the field is required. In addition, the contractor should be required to present a prototype installation of each subsystem including roadside and in-vehicle components and complete operational testing of all prototype components as necessary. Finally, a maintenance agreement with a contractor

should be established to deal with system/equipment challenges and malfunctions (if any) during the field test period. Because of the limited number of full time signal technician staff in the Burlington area, contracting out this quality control function during the field test may be essential depending on the current workload of the local signal technicians.

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Introduction

Advancements in traffic signal technologies and other factors have generated a great deal of interest in the provision of preferential traffic signal strategies and treatments for transit buses and other vehicles at signalized intersections. In order to plan and deploy such signal priority strategies and treatments safely and efficiently, careful analyses should be conducted using fundamental traffic engineering and transit management and operating principles. To this end, this project intends to provide guidance based on these principles and other considerations to aid in planning and deploying signal priority strategies for bus transit in Vermont, where appropriate.

Project Goal

The primary goal of this project is to assist the Vermont Agency on Transportation (VAOT), regional agencies, and local jurisdictions in considering the use of traffic signal systems and technologies to implement traffic signal priority strategies for buses. The study includes an evaluation of the impacts, merits, and limitations associated with alternative traffic signal priority strategies and a review of the lessons learned in communities similar to those in Vermont where such strategies have been deployed. An underlying aim of the project is to assist VAOT and other public agencies in the State in planning and deploying signal priority strategies for transit buses in concert with other preferential signal treatments such as those currently in place and being planned for fire and rescue services. The coordination of traffic signal priority strategies for multiple types of vehicles is of utmost importance to preserve safety, enhance traffic flow, and improve mobility.

Scope of Work

The scope of work includes four major tasks:

1. Identify and review institutional issues and concerns, stakeholders, and vehicle priority needs and requirements

2. Conduct a simulation analysis evaluation of alternative transit priority strategies at signalized intersections on selected arterials in the State.

3. Perform a small scale field test along an arterial in the Burlington area as deemed necessary in Task 1 and based on the results of Task 2. The intent of this test would be to supplement, as needed, the simulation analyses in Task 2 so that the impacts of transit priority strategies at signalized intersections may be examined further. However, it was decided that the field test would not be carried out because the planned investment on priority equipment was postponed to Fiscal Year 2008.

4. Develop a set of guidelines to assist the VAOT, local jurisdictions, transportation agencies, and public safety agencies in the planning and design of transit priority strategies and treatments along signalized arterials in the State.

Task 1 – Identify and Review of Institutional Issues, Stakeholders, Needs and Requirements

Task 1 included an identification and review of institutional issues and concerns, stakeholders, and transit priority needs and requirements. To this end, Task 1 was divided into two sub-tasks. Sub-task 1a included a synthesis of technical reports and policy and deployment studies to assist in the identification of institutional issues, stakeholders, and system requirements associated with the design and implementation of transit priority strategies and levels along signalized arterial streets in the State. A special effort was made to review literature documenting the systems design of transit priority strategies and the results and lessons learned on signal preemption/priority projects in the U.S. and abroad. Task 2b included the conduct of meetings and interviews with stakeholders including state and local traffic, transit, and other officials and other interested individuals as necessary to examine the issues, concerns, and needs/requirements regarding the potential use of alternative transit priority strategies in the Chittenden County area.

Sub-Task 1a. Literature Synthesis

Transit Signal Priority and Objectives

According to the Transit Signal Priority Handbook (1), transit signal priority is defined as "*an operational strategy that facilitates the movement of transit vehicles (usually those in service), either buses or streetcars, through traffic-signal controlled intersections.*" One of the main objectives of transit priority is to reduce excessive transit delay at traffic signals of particular intersections (2). Another objective is to reduce excessive transit delay along particular corridors due to traffic congestion. Other objectives focus on improvements in transit reliability through schedule adherence, headway adjustments, and fleet and labor management.

Transit Signal Priority and Emergency Vehicle Preemption

Transit signal priority and emergency vehicle preemption use similar equipment and that is the main reason that many people tend to consider them synonymous, but, in fact, they are different. For the purposes of this study, emergency vehicle preemption is the transfer of the normal operation of traffic signals to a special signal control mode for the purpose of servicing one or more emergency vehicle passage, the control of which requires terminating normal traffic control to provide for the emergency vehicle service needs. Transit signal priority is defined as the preferential treatment of a single transit vehicle at a signalized intersection depending on one or more conditions; such conditions may include, for example, the presence of a green interval and the degree of vehicle lateness and /or occupancy.

Transit Signal Priority Strategies

Transit signal priority can be implemented in various ways. The three main categories are passive, active and adaptive priority (1).

Passive priority is provided continuously and does not require transit detection and any hardware and software components. This type of priority is applicable when transit operations are predictable and when transit routes, passenger loads, schedule and dwell times are known. One possible strategy is the establishment of signal progression for transit. In this case signals are planned to operate according to various characteristics, such as dwell times at transit stops. An example of that strategy is in Denver where cycle lengths are based on the travel speed of buses on the Denver Transit Mall (1).

Because traffic signals are designed to improve the overall traffic flow including transit, consideration should be given to overall traffic delays before applying transit priority. Such considerations should include retiming signal timing plans, reducing cycle lengths and coordinating signals on a corridor.

Active priority is provided to specific transit vehicles that are detected and/or request priority. Types of strategies included in active priority are summarized below (1).

A green extension is an active priority strategy that extends the green time for the transit vehicle that approaches the signal while it is green. A green extension is considered one of the most effective forms of transit priority since it does not require additional clearance intervals and usually reduces transit vehicle delays at intersections.

An early green (or red truncation) is another active priority strategy that shortens the green time of preceding phases to expedite the return to green for the movement of the transit vehicle. This type of strategy is applicable when the signal is red for the approaching transit vehicle.

Actuated transit phases are displayed only when a transit vehicle is detected at the intersection. An example of such strategy is the exclusive left turn phase which is displayed only when a transit vehicle is detected in the lane. Another example is the queue jump phase that would allow a transit vehicle to enter the downstream traffic ahead of the normal traffic stream. This strategy shows a signal that is intended only for the transit vehicle and allows the vehicle to move ahead of the other traffic.

Phase insertion is another active strategy when a special transit phase is inserted within the normal signal sequence. The phase can be inserted only if a transit vehicle is detected and requests priority. An example of this strategy is the insertion of a leading left-turn-only phase.

Finally, phase rotation serves to rotate the order of signal phases to provide priority to a transit vehicle. For example, a left-turn lagging phase, which typically follows the opposing through phase, could be served as a leading phase if a transit vehicle is detected in the turning lane.

Adaptive priority treatments are very sophisticated and complex and, therefore, are not widely used. They can be divided into two main categories (1):

Transit Priority with Adaptive Signal Control Systems provides priority while simultaneously optimizing given traffic performance. These systems continuously monitor traffic conditions and adjust signal control strategies. These systems account for person delay, transit delay, vehicle delay and a combination of these. Adaptive signal control systems require early detection of the transit vehicle in order to provide more time to adjust the signals to provide priority while minimizing overall traffic impacts.

Adaptive Signal Priority takes into account the trade-offs between transit and traffic delay and allows adjustments in signal timing by adapting the movement of the transit vehicle and the prevailing traffic condition.

Transit Signal Priority Architecture

A systems engineering concept central to the design of any intelligent transportation system includes the system architecture which depicts the structure of a system design. The architecture type may be logical or physical (3). A logical architecture, depicted in Figure 1, represents the flow of data in a typical signal priority and preemption system.

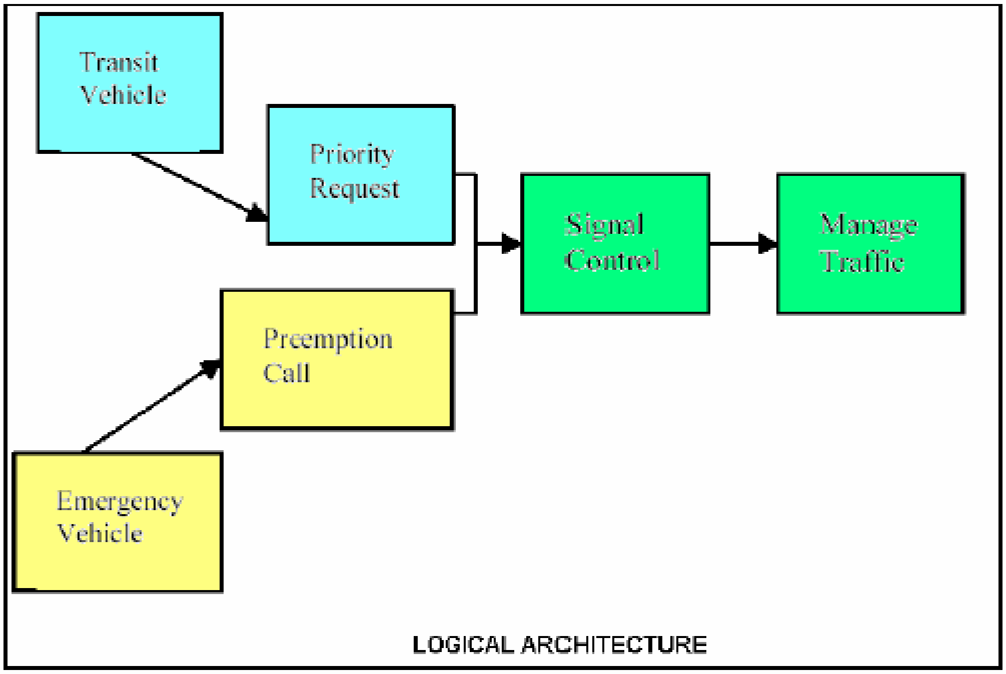


FIGURE 1 General Logical Architecture for a Transit Priority System (4)

A physical architecture represents the subsystems of the system (3). In general, as it is defined by the U.S. Department of Transportation in the National ITS Architecture, physical architecture consists of four subsystems: the travelers; the centers; the roadside; and the vehicle (3). These sub-systems consist of one or more components that are typically connected through wired and wireless telecommunications systems (4). The physical architecture and the components (see shaded items, Figure 2) involved in transit signal priority are presented in Figure 2.

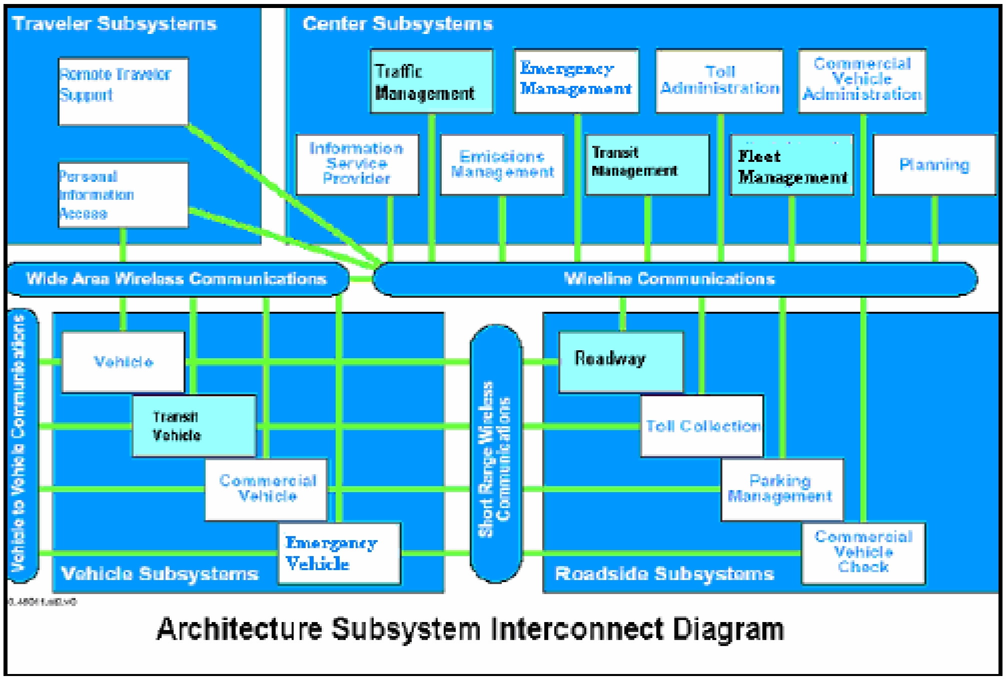


FIGURE 2 General Physical Architecture of a Transit Signal Priority System (4)

The roadway subsystem consists of the traffic signals, the signal controllers, and the detectors. The vehicle subsystem includes the vehicles and emitters and possibly other ITS technologies such as automatic vehicle location (AVL) and automatic passenger counter (APC) (4).

The center subsystem might consist of transit management and traffic management centers. The first supports transit operational functions while the latter manages the movement of traffic, including transit and other vehicles along roadways (3). In the case that AVL and APC technologies are present, the fleet management center is also included in the architecture (4). Under an advanced priority system design, a transit management center might be required to request priority authorization from the traffic management center. In this instance these two centers are more likely to communicate via a wire line connection, whereas the transit management center would likely communicate with the transit vehicles via a wide area wireless communication system (3).

Transit Signal Priority System

A relatively simple transit signal priority and emergency vehicle preemption system is presented in Figure 3.

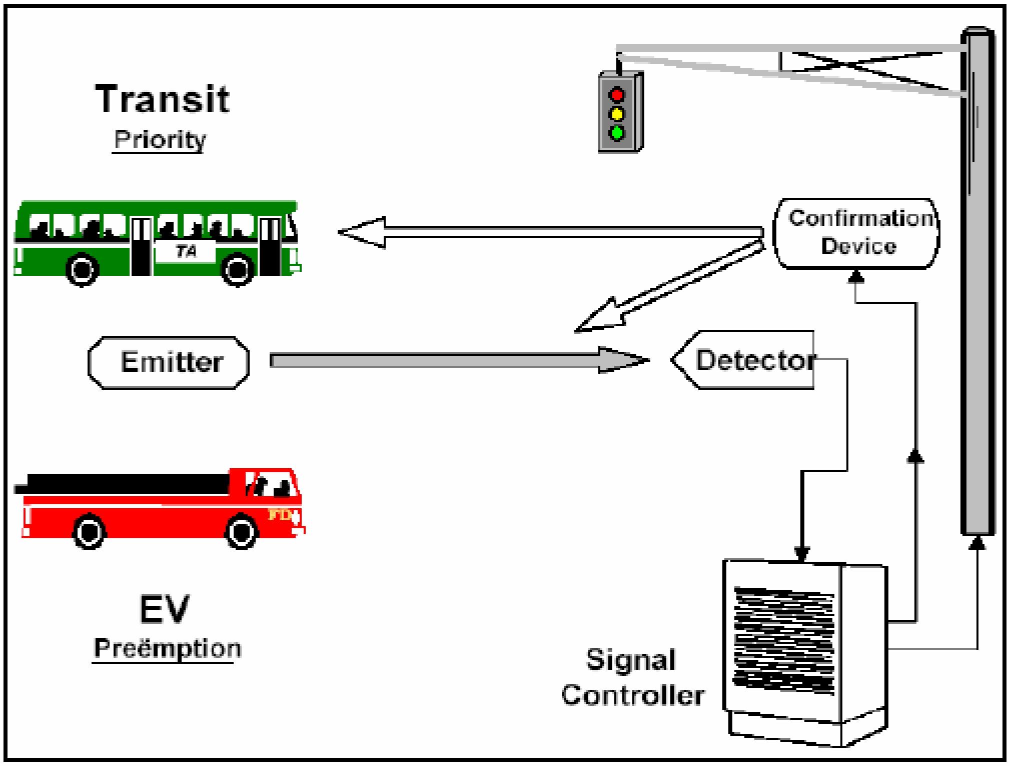


FIGURE 3 Transit Signal Priority System (4)

This system design includes emitters on-board the transit and emergency vehicles that send strobe-based signals to a detector at the intersection. The detector passes on the message to the signal controller to request priority or preemption. Systems are often designed and deployed in an "encoded" manner, requiring all vehicles to be uniquely identified and thus minimize the number of authorized users. When priority is requested and a green interval exists in the direction of transit vehicle travel, the green interval may be extended as needed to allow the transit vehicle to clear the intersection. If a red interval exists, this interval might be truncated by shortening green intervals of other signal phases while still maintaining proper clearance times (3). It should be noted that if transit priority is requested during an emergency vehicle request, the transit priority request is ignored.

Case Studies and Results

Numerous studies conducted in small, medium, and large urban areas in the U.S. used simulation to evaluate the anticipated impacts of transit priority deployments. These studies are summarized in Table 1 (5, 6). Bus travel time is a common measure used to assess the impact of transit priority. As shown in Table 1, bus travel time decreased from 0.9% in Arlington, VA (2003) to 32% in Washington, DC (1975). Other measures used in Table 1 are the overall vehicle-delay, the stopped delay/vehicle and the impacts to non-transit vehicles. The simulation models most frequently used include VISSIM, TRANSYT, NETSIM, INTEGRATION, and SCOOT.

A more recent study not included in Table 1 used VISSIM to identify the impacts of TSP along the U.S. 1 corridor in Northern Virginia (4). The measures of effectiveness used were transit travel time, bus control delay and queue length on side streets. The outcomes showed that transit travel time decreased from 0.8% to 4%, bus control delay reduction ranged between 5% and 16% and total queue length increased around 1.23%.

TABLE 1 Results of Transit Priority Projects in the U.S. Using Simulation (5, 6)

U.S. Experiences	**Measure**	**Result**
Simulation Studies		
Fairfax, VA-U.S.1 VISSIM	Bus Travel Time	2.64% decrease
	Time Reliability	3.61% improvement
	Average Queue Length on Side Street	1.28 ft increase (less than one car length) Not significant
Arlington, VA Columbia Pike Blvd INTEGRATION	Bus Travel Time	0.9% decrease
	Arrival Reliability	3.2% improvement
	Overall Vehicle-Delay	1% increase
Arlington, VA Columbia Pike Blvd SCOOT/INTEGRATION	Bus Travel Time	6% decrease
	Overall Person-Delay	8% increase
Bremerton, WA	Bus Travel Time	10% decrease

	Stopped Delay/Vehicle	Not significant
Baltimore, MD TRANSYT	Light Rail Operating Speeds	7% decrease
	Individual Vehicle Delay	14% increase
Seattle, WA TRAF-NETSIM	Bus Delay	33% decrease
	Impacts to Private Vehicles	Minimal
Washington, DC UTCS-1	Bus Travel Time	22 to 32% decrease
	Cross Street Traffic Travel Time	6-30% increase(far-side stops) 9-66% increase (near-side stops)
Ann Arbor, Michigan NETSIM/TRANSYT-7F	Bus Travel Time	6% decrease (for a single bus)
Austin, Texas NETSIM	Bus Travel Time	11% decrease (optimized lower cycle length 10% decrease (phase splitting)
Chicago, IL TRAF-NETSIM /TRANSYT-7F	Bus Travel Speed	24% increase
	Bus Travel Time	30% decrease
Dallas, Texas VISSIM	Bus Travel Time	2 to 11% decrease
	Vehicle Travel Time	1 to16% decrease
	Overall Vehicle-Delay	2.8 to 3.7% decrease
	Overall Person-Delay	4.1 to 6.1% decrease

Numerous field studies conducted in small, medium, and large urban areas in the U.S. are summarized in Table 2 (5, 7). These studies concluded that bus travel decreased from 1.4% in Portland, OR (1996) to 38% in Minneapolis, MN (1996). Another measure, bus signal delay, decreased from 20% in Portland, OR (1996) to 57% in Seattle, WA (1999). Measures such as vehicle/person delay, cross street delays, side street effects most often showed few significant impacts.

In conjunction with the simulation analysis mentioned above, a field-study was conducted on U.S. 1 in Northern Virginia (2). A ten second green extension demonstrated an overall travel time decrease from 3% to 6%. During peak travel time, intersection delays decreased between 9.26%

and 23%. Reduction during non peak hours was around 10.17%, while reduction during the entire AM analysis period was 13.3%.

TABLE 2 Results of Transit Priority Field Studies in the U.S. (5, 7)

U.S Experiences	**Measure**	**Result**
Field Studies		
Portland, OR (2002) Tri-Met BDS/AVL Line 12 Bardur	Median Run Time	Up to 3 minute-decrease (before and after analyses)
	Coefficient of Variation	Up to 3.5% decline (before and after analyses)
Portland, OR (2002) Tri-Met BDS/AVL Route 4 Fessenden	Median Run Time	Up to 46 second-decrease (before and after analyses)
	Coefficient of Variation	Up to 7% decline (before and after analyses)
Charlotte, NC / OPTICOM (Express Buses)	Bus Travel Time	4 minute decrease
	Cross Street Delays	Not acceptable
Portland, OR TOTE&LoopComm Tests	Bus Travel Time	5 to 8% decrease
	Vehicle or Person Delay	Not significant
Portland, OR Tualatin Valley Highway	Bus Travel Time	1.4 to 6.4% decrease
	Bus Signal Delay	20% decrease
Portland, OR Pilot Routes	Bus Travel Time	10% decrease
	On Time Performance	8 to 10% improvement
Chicago, IL Cermak Road	Bus Travel Time	7-20% decrease
	Cross Street Delays	8.2 seconds/vehicle
Minneapolis, MN Louisiana Ave Opticom	Bus Travel Time	38% decrease (High Priority) No change (Medium or Low Priority)
	Auto Stopped Delay	23% decrease (High Priority) No Change (Medium or Low Priority)
Portland, OR Route 12 AVL	Inbound Travel Time	0.4 to 2.3% increase
	Outbound Travel Time	1.5 to 4.2% increase
	Bus Speed	2.9 to 13.7% increase
St. Cloud, Stearns County, MN	Bus Delay	43% decrease
	Average Bus Occupancy	24
	Bus Travel Time	13 to 18% decrease
Anne Arundel County, MD MDSHA Opticom	Auto Travel Time-Same Direction	9% decrease

	Auto Travel Time-Opposing Direction	4 to 5% increase
Los Angeles, CA Metro Rapid	Bus Travel Time	8 to 10% decrease
Los Angeles, LADOT	Bus Travel Time	22 to 27% decrease
San Francisco, CA	LRT and Trolleys Travel Time	6 to 25% decrease
San Diego, CA	Trolley Travel Time	2 to 3 minute decrease over a section of 4.8 km
Seattle, WA Rainier at Genesse	Bus Signal Delay	57% decrease
	Bus Intersection Stops	50% decrease
	Bus Travel Time Variability	35% decrease
	Intersection Person Delay	13.5% decrease
	Side Street Effects	Not significant
Seattle, WA Rainier Avenue	Priority Bus Delay	34% decrease
	Bus Intersection Stops	24% decrease
	Bus Travel Time	8% decrease
Tacoma, WA Pierce Transit Agency Opticom	Bus Travel Time	5.8-9.7% decrease (green extension) 8.2% decrease (green extension and/or early green)
	Side Street Impacts	Not significant

Finally, many field studies and simulation analyses conducted outside the U.S. – mostly in Europe – are summarized in Table 3 (5, 8). The most commonly used MOE was bus travel time observing a decrease between 4% in Strasbourg, France (2001) and 23.8% in Vicenza, Italy (2001). Other measures of effectiveness used were bus signal stopped time with a 20.8% decrease in Japan (1996), bus delay with a 5% to 20% decrease in London, England (1999), and overall traffic travel time with no significant change in Toulouse, France (2001). The findings in these studies are consistent with those in the U.S. and provide additional evidence regarding the beneficial impacts of transit priority without significantly impacting overall traffic.

TABLE 3 Results of Transit Priority Projects Outside the U.S. (5, 8)

Experiences Outside U.S.	Measure	Result
Vicenza, Italy Opticom	Bus Travel Time	23.8% decrease
	Bus Travel Speed	30% increase
Swansea, England SCOOT	Bus Travel Time	2% decrease (passive priority) 11% decrease (green extension/red truncation) No change (green extension)
	Non Transit Vehicle Delay	17% increase (passive priority) 7% increase (green extension/red truncation) 15% increase (green extension)
Leeds, England SPOT	Bus Travel Time	10% decrease
	Non Transit Vehicle Travel Time	No Change
Stuttgart, Germany	Light Rail Transit Delay	50% decrease (conditional priority)
	Private Vehicle Delay	Minimal
Toulouse, France	Bus Travel Time	11 to 14% decrease
	General Traffic Travel Time	Not significant change
Strasbourg, France	Transit Vehicle Travel Time	4 to 5% decrease
Zurich, Switzerland	Bus Waiting Time	Zero (at 90% of signalized intersections
Toronto, Canada	Street Car Signal Delay	15 to 49% decrease
Sapporo City, Japan	Bus Travel Time	6.1% decrease
	Bus Signal Stopped Time	20.8% decrease
London, England SCOOT	Bus Delay	5 to 20% decrease
	Bus Delay Variability	4 to 12% decrease

Sub-Task 1b. Meetings with State and Local Officials

Two meetings were held with State and local officials and other interested individuals to identify and review institutional concerns and associated technical issues, stakeholders' interests, and transit priority needs and requirements. One meeting was held in July 2005 and another was held in January 2006. A list of the major transit priority stakeholders is provided in Appendix A. In addition to these meetings, follow-up discussions were carried out with key individuals in person and by phone during the course of the project. These individuals include Aaron Frank of the CCTA, Susan Schimenko, CCMPO, David Roberts, CCMPO, and Bruce Nyquist, VTrans.

At present, no transit signal priority strategies are in place in the Chittenden County area. However, there are two different emergency vehicle preemption signal systems currently in place at some 25 signalized locations. These systems are provided by two private vendors, 3M and Tomar. While both 3M's and Tomar's systems are designed to also accommodate transit priority, the two systems are not interoperable unless they both are allowed to operate in an "unencoded" manner. As indicated above in the literature synthesis, operating in an "unencoded" manner means that any vehicle emitting an optical signal at the proper signal frequency will be given priority, which is generally viewed as less than desirable for the fear that the priority feature might then be abused by unauthorized users. Ideally, traffic signals providing preferential treatment should do so by requiring not only the proper signal frequency but also a unique vehicle identification code. The conclusions at the end of the January 2007 meeting were that the two different systems should be allowed to operate in the short term in an "unencoded" manner and that should the "unencoded" mode of operation be abused by unauthorized users the "unencoded" mode would be terminated. As shown in Appendix B, the CCMPO policy to achieve system interoperability is to migrate to one system at which time that system would operate in an "encoded" manner with greater security and vehicle logging and tracking capabilities. Appendix C lists locations of 3M and Tomar systems.

Another local issue of concern surrounded the lack of consensus regarding the intended objectives, expectations, and potential undesirable impacts pertaining to the provision of transit priority. Some local officials viewed transit authority as a means to simply improve bus schedule adherence, while others viewed transit priority as a means of improving the quality of bus service in order to increase ridership. In addition, other individuals expressed the concern that transit priority might disrupt traffic signal timing plans and unnecessarily cause delays for large numbers of motorists. In order to address this issue and ensure that transit priority strategies are planned and deployed properly there is a need to articulate transit priority objectives clearly and to formulate a set of evaluation criteria to systematically assess the impacts of priority strategies. Such criteria are used in the simulation analyses in Task 3 and are proposed for use in the recommended field test.

Task 2 – Conduct a Simulation Analysis

Task 2 included simulation analyses to evaluate alternative transit priority strategies along two major bus routes: 1) the Old North End Loop in downtown Burlington, and 2) the bus route along Route 15. Simulation analyses were conducted with the use of VISSIM, a commercially available simulation software package designed to evaluate the performance of transit priority strategies. The strategies considered consisted of a 10 second green extension and did not include any red truncation. In some strategies the relocation of bus stops from the nearside to the farside was also considered. Data required for the simulation analyses were obtained from readily available Synchro files, other existing data sources, and field observations as part of this project. Basic simulation concepts and the major findings and results of the simulation analyses are presented below. For further details on the simulation analyses, see Mermelstein (11) and Vlachou (9).

Simulation

As defined in the transit signal priority Handbook (1), simulation is the process of replicating a real world situation with a computer model. The model is used to aid in predicting the impacts of transit priority strategies based on interactions between system sub-systems. Two major sub-systems are the traffic (including buses and other vehicles) and the roadside infrastructure (including streets, traffic signals, bus stops, and crosswalks). The impacts of the transit priority strategy can be quantified using a variety of measures as described in Tasks 1 and 3.

Advantages of Simulation

Simulation can be a very useful tool for evaluating the impacts of alternative transit priority strategies. Some of the advantages of simulation as presented in the Handbook are:

- Providing a cost effective way of testing and evaluating different strategies
- Allowing planners and engineers to examine alternative strategies faster than in a real world environment
- Offering insights associated with the effects of varying traffic flow characteristics thus potentially leading to more informed decisions
- Providing outputs in graphical and visually animated formats that policy makers and the general public can more easily understand.

VISSIM

The simulation model used in this research project was VISSIM, a commercially available microscopic level, stochastic based simulation model. VISSIM Version 4.10 has features that facilitate the evaluation of alternative transit priority strategies including simple network editing; easy setup and import of partial networks from Synchro, another commonly used simulation model employed in the Chittenden County area; sophisticated vehicle behavior modeling; graphical visualization and animation capabilities; and multiple analysis options. For more details on VISSIM see www.ptvamerica.com/vissim.html.

Using VISSIM to Model Transit Priority Strategies along Route15

An initial step taken as part of the VISSIM simulation analyses along Route 15 was to obtain Synchro files from the Chittenden County Metropolitan Planning Organization. For the purposes of this research the AM Peak was chosen as the analysis period, the Synchro network for which is shown in Figure 4. Another major source of information was the bus schedule for bus service along Route 15. The resulting VISSIM network is presented in Figure 5.

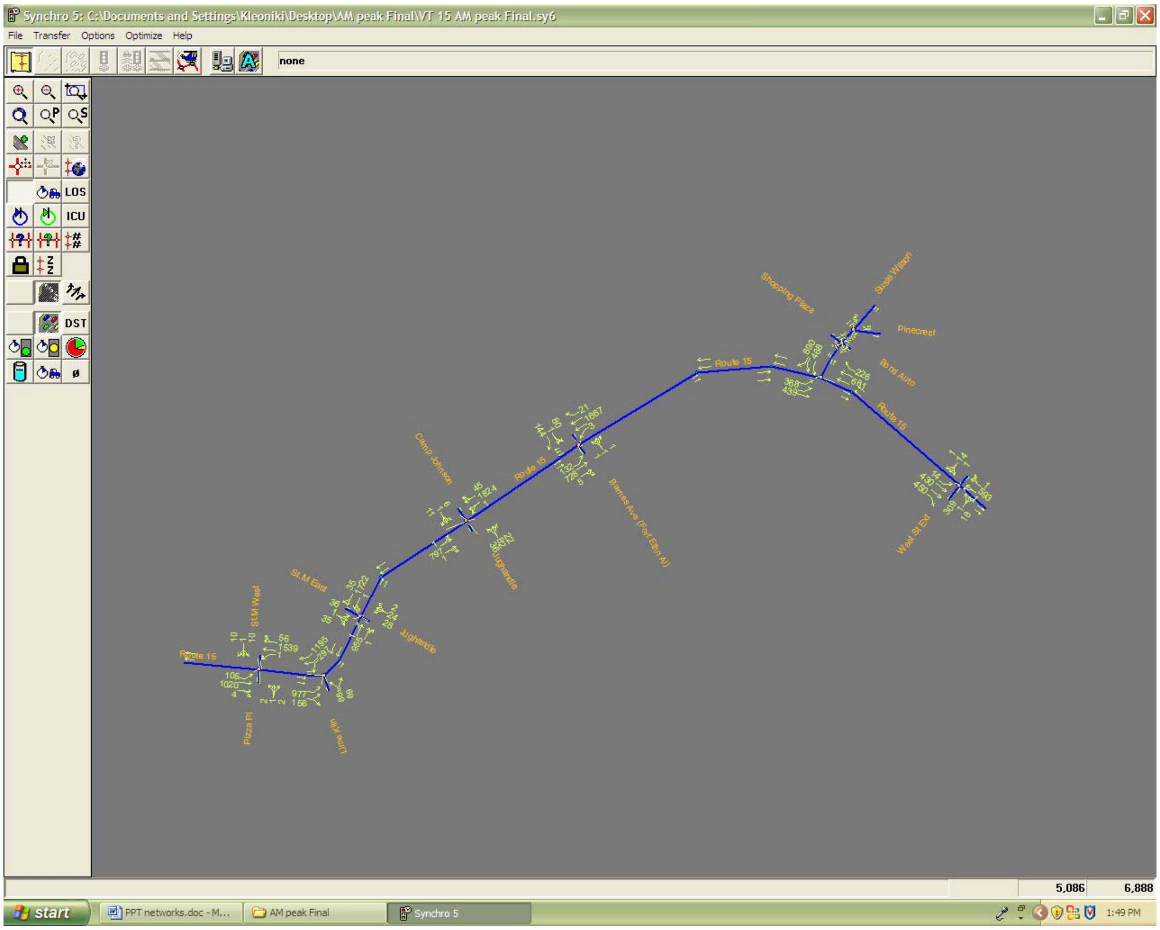


FIGURE 4 Route 15 AM Peak Synchro File

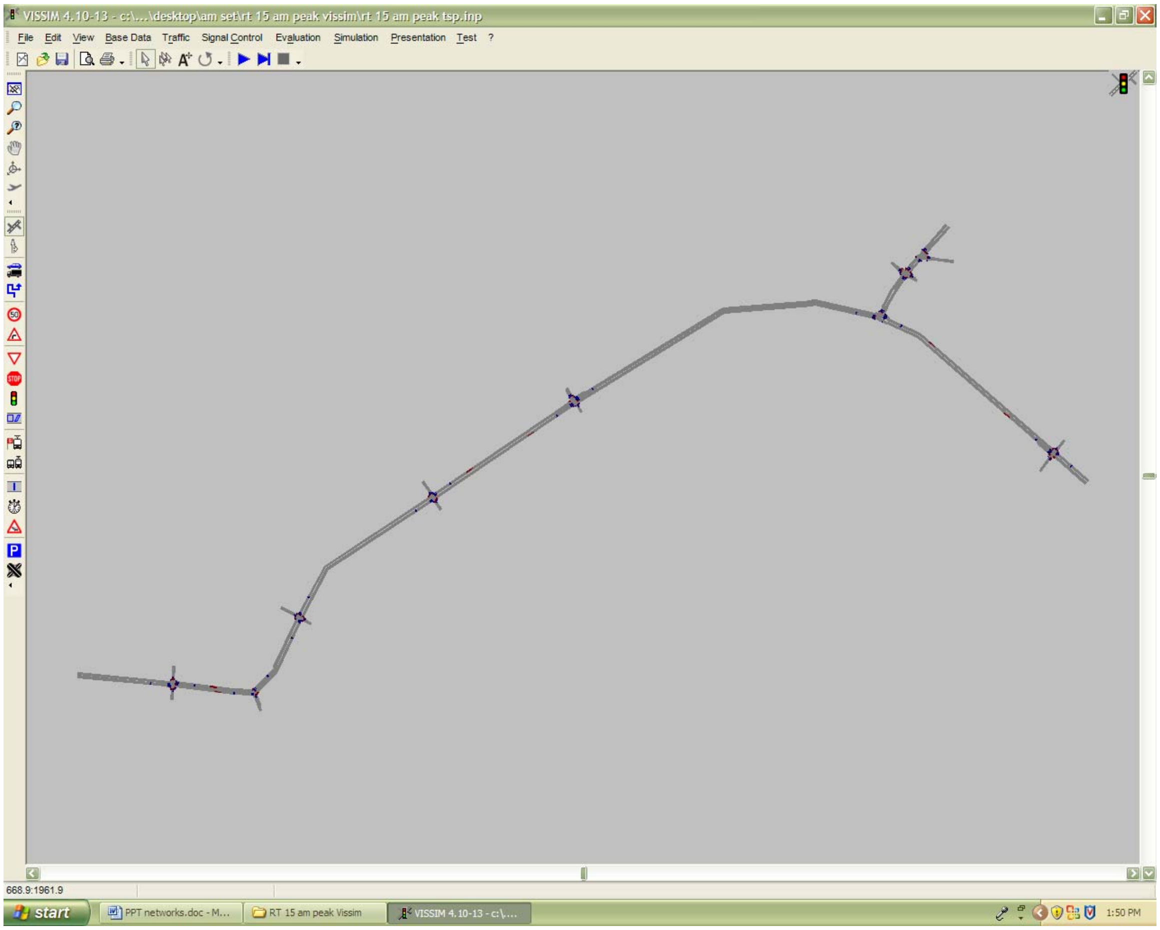


FIGURE 5 Route 15 VISSIM Network

Assumptions

As is typically the case in simulation analyses, several assumptions were made as part of this simulation analysis including:

- Only the inbound bus service will request a priority.
- Bus stop locations were established on the VISSIM file based on field observations and a review of the bus schedules.
- Dwell times follow a normal distribution with a mean value of thirty seconds and a standard deviation of five seconds.
- An average bus speed was assumed to be 25 miles per hour.
- The transit check-in and check-out detectors are placed in the network such that the travel times between the two detectors are equal to the desired maximum green extension time. Since the mean speed of buses is 25 miles per hour and the maximum green extension time is 10 seconds, the distance between the check-in and check-out detectors was set at 365 feet throughout the entire network.

Transit Priority Scenarios and Evaluation Measures

For the purpose of this research two transit priority scenarios along Route 15 were evaluated. One included a ten second green extension for the AM buses in the inbound direction assumed to be operating under existing conditions including approximate 30 minute headways. In the second scenario the inbound buses also may request a 10 second green extension but the headways were changed to 15 minutes, reflecting the interest among local stakeholders to improve the frequency of bus service along selected bus routes in the Region. Four major categories of evaluation measures were employed in this simulation analysis: 1) **travel time** for the bus and car; 2) **delay** to the bus and car; 3) **waiting time** for outbound buses; and 4) **side street queue length**.

Simulation Results

The average values for each evaluation measure were calculated based on twenty runs for the first scenario and eight runs for the second scenario. A statistical analysis using the Student's t test was first conducted for the absolute values of the samples, followed by a second statistical analysis on the difference of the values. More details on this analysis are presented in Vlachou (9).

Travel time

Travel time as it is defined in the VISSIM Manual (10), is measured in seconds and represents the time required for a vehicle to travel between the first cross-section (start) of the network and the second cross-section (destination), including waiting or dwell times.

Bus Travel Time

The average bus travel times for each scenario comparing the base case (i.e. without priority to with priority) are shown in Figure 6. Table 4 presents for each scenario the rate of change in average bus travel times without and with transit signal priority. In the first scenario it appears that the reduction in average bus travel time with priority is 4.6% and for the second scenario this reduction is 5.8%. It should be noted that in the first scenario the t-statistic of the absolute values shows that the difference of the means in not statistically significant but that the t-statistic of the differences of the values shows that the difference is significant. For the second scenario both t-tests showed that the difference of the means is not statistically significant.

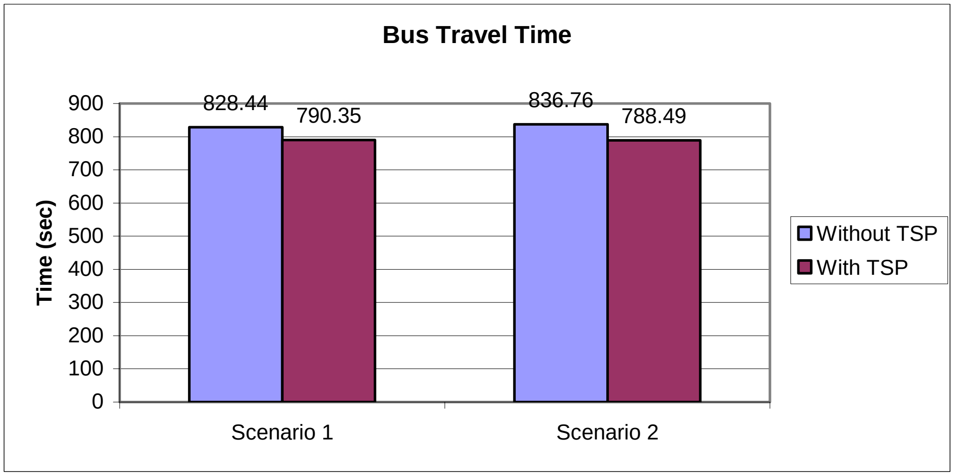


FIGURE 6 Average Bus Travel Time (in seconds)

TABLE 4 Rates of Change in Bus Travel Time (in seconds)

	Bus Travel Time (sec)		
	Without TSP	**With TSP**	**Rate of Change**
Scenario 1	828.44	790.35	-4.60%
Scenario 2	836.76	788.49	-5.77%

Car Travel Time

The computed car travel time is for those cars (and other vehicles) that move in the same direction as the buses that have the ability to request priority. The comparison of the average travel time of cars in each scenario is shown in Figure 7, and the comparisons of the rates of change appear in Table 5. In the first scenario the reduction of rates of change in car travel time is estimated to be about 0.3% and for the second scenario about 6.3%, neither of which, based on the t test analysis, proves to be statistically significant.

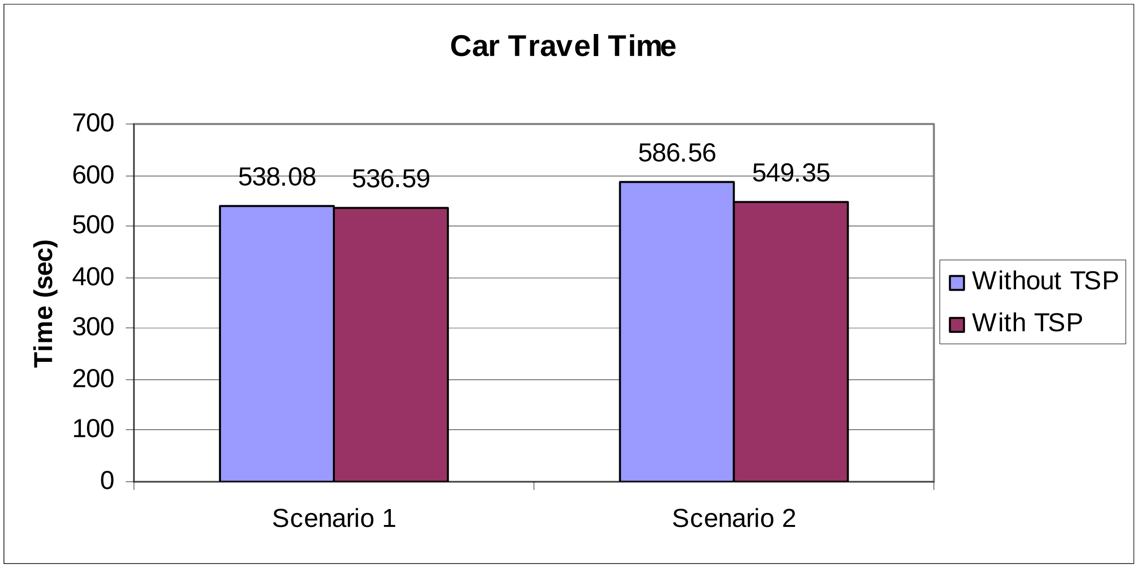


FIGURE 7 Average Car Travel Time (in seconds)

TABLE 5 Rates of Change in Car Travel Time (in seconds)

	Car Travel Time (sec)		
	Without TSP	**With TSP**	**Rate of Change**
Scenario 1	538.08	536.59	-0.28%
Scenario 2	586.56	549.35	-6.34%

Delay

As defined in the VISSIM Manual (10), the average total delay per vehicle, measured in seconds, is computed for every vehicle completing the travel time section by subtracting the theoretical (ideal) travel time from the real travel time. The theoretical travel time is the time that would be reached if there were no other vehicles and no signal controls or other stops in the network (reduced speed areas are taken into account). The delay does not include passenger stop times at transit stops. However, the loss time caused by acceleration or deceleration because of such a stop remains part of the delay time.

Bus Delay

The values of bus delay and the rate of change for each scenario with and without transit priority are shown in Figure 8 and Table 6, respectively. The results suggest that in the first scenario there is a 14.2% reduction of bus delay for the buses with priority and a reduction of 16.5% in the second scenario when priority is provided. The t-test analysis shows that the difference of the average values for the first scenario is statistically significant and that the second scenario difference of the average values was not statistically significant. The t-test for the difference of the rates of change showed that the difference of the means is statistically significant.

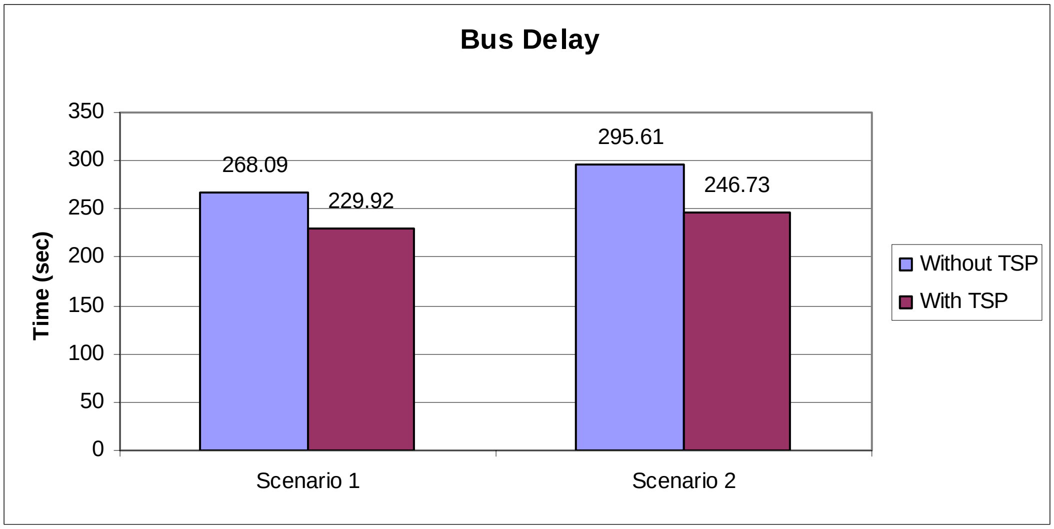


FIGURE 8 Average Bus Delay (in seconds)

TABLE 6 Rates of Change in Bus Delay (in seconds)

	Bus Delay (sec)		
	Without TSP	**With TSP**	**Rate of Change**
Scenario 1	268.09	229.92	-14.24%
Scenario 2	295.61	246.73	-16.54%

<u>Car Delay</u>

The average car delay computed for each scenario with and without priority is presented in Figure 9 and the corresponding rates of change are in Table 7. The reduction of the rates of change in delay of the cars that travel in the same direction as the buses that get priority is about 1.1% in the first scenario and about 9.5% in the second scenario. In both scenarios the statistical analysis of the average values and the rates of change showed that the differences of the means are not statistically significant.

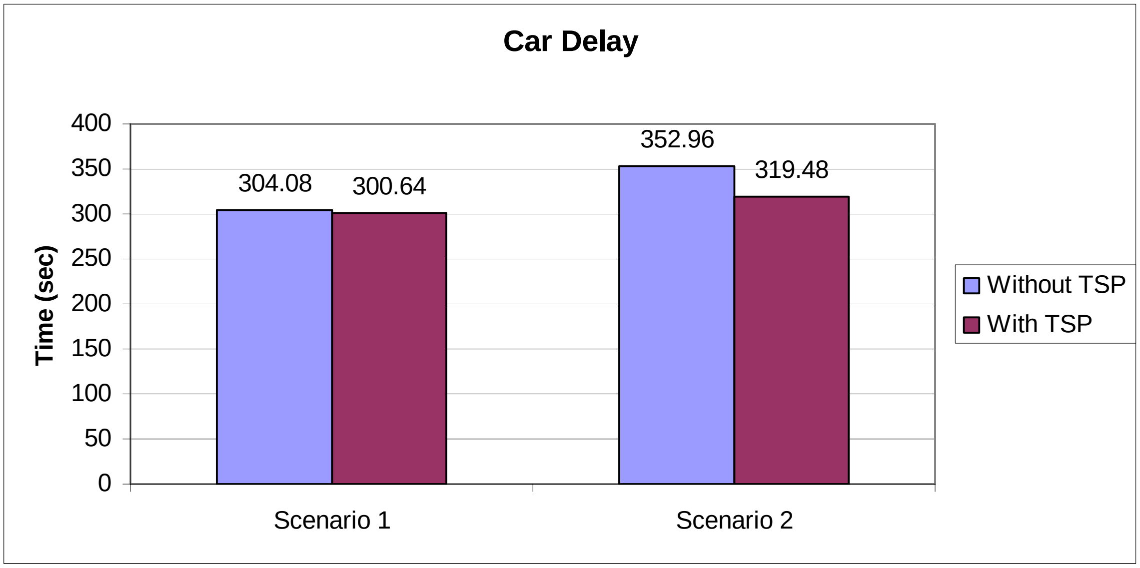


FIGURE 9 Average Car Delay (in seconds)

TABLE 7 Rates of Change in Car Delay (in seconds)

	Car Delay (sec)		
	Without TSP	**With TSP**	**Rate of Change**
Scenario 1	304.08	300.64	-1.13%
Scenario 2	352.96	319.48	-9.49%

Bus Waiting Time

Bus waiting time computed in seconds, consists of all events when a transit vehicle is stopped, excluding passenger interchange stops and stops at stop signs.

Bus Waiting Time-Outbound Buses

The outbound buses travel in the non peak direction and do not get priority. The average bus waiting time outbound is shown in the Figure 10. Table 8 presents the rates of change appears in outbound bus waiting time. In both scenarios there appears to be an increase in the waiting time of the outbound line when priority is provided. This increase was about 12.4% for the first scenario and 4.1% for the second. For both scenarios it was shown that these increases are not statistically significant.

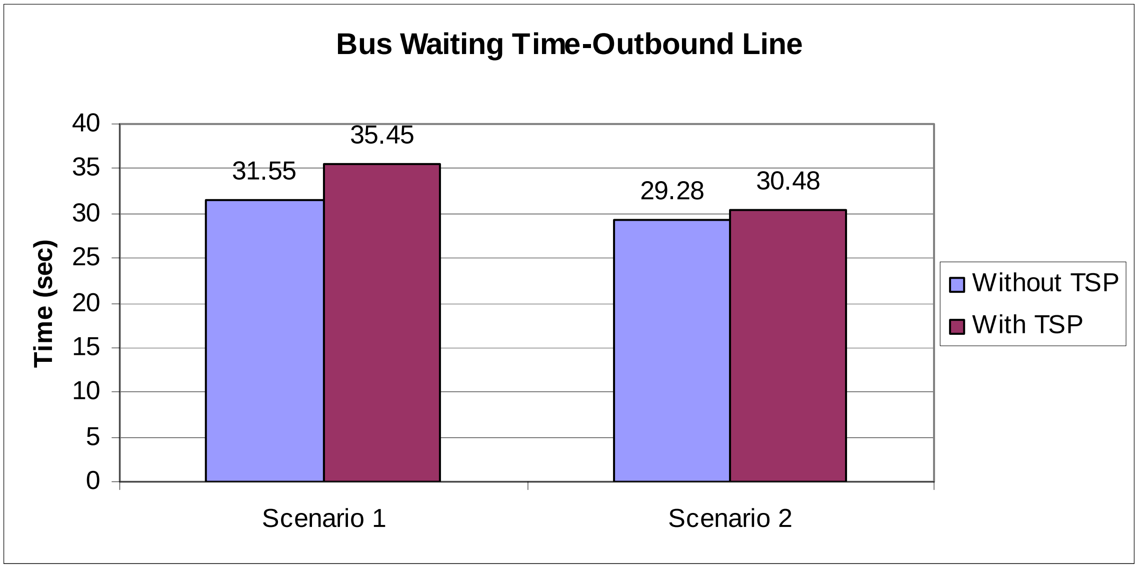


FIGURE 10 Average Bus Waiting Time-Outbound Line (in seconds)

TABLE 8 Rates of Change in Bus Waiting Time-Outbound Buses (in seconds)

	Waiting Time-Outbound (sec)		
	Without TSP	**With TSP**	**Rate of Change**
Scenario 1	31.55	35.45	12.36%
Scenario 2	29.28	30.48	4.10%

Bus Waiting Time-Inbound Buses

As indicated above, the inbound line is in the peak direction and gets priority. The average waiting times of these buses are depicted in Figure 11. The values of waiting times for each scenario appear in Table 9. In the first scenario the reduction in the rate of change in the waiting time estimated is about 27.9% and this reduction in the second scenario is about 27.3%. In both scenarios the estimates are statistically significant.

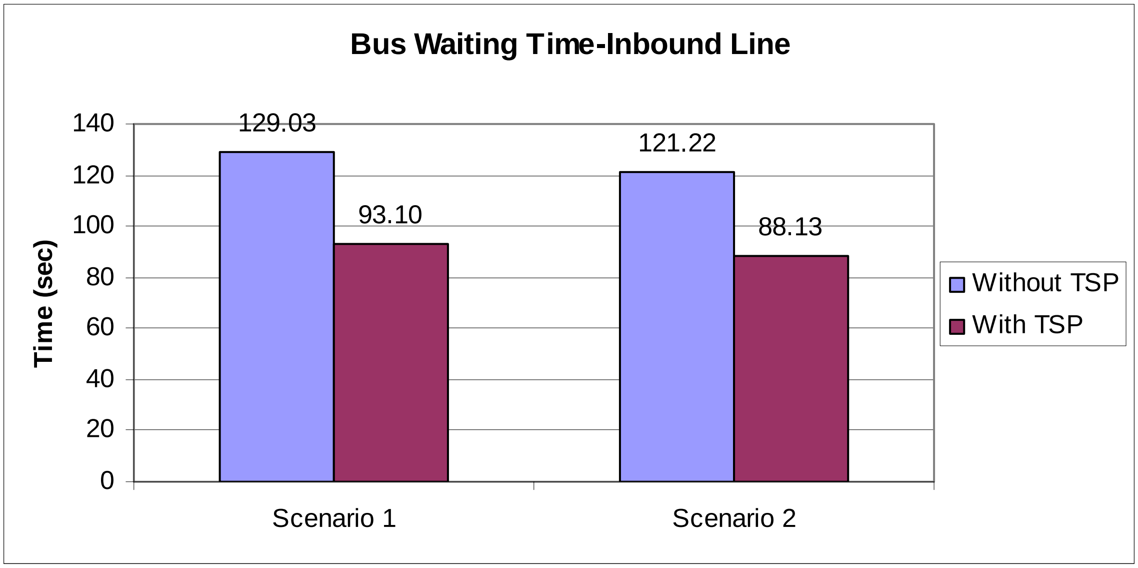


FIGURE 11 Average Bus Waiting Time-Inbound Buses (in seconds)

TABLE 9 Rates of Change in Bus Waiting Time-Inbound Buses (in seconds)

	Waiting Time-Line 2 (sec)		
	Without TSP	**With TSP**	**Rate of Change**
Scenario 1	129.03	93.10	-27.85%
Scenario 2	121.22	88.13	-27.30%

Side Street Queue Length

The maximum queue length, according to the VISSIM Manual (10) is the maximum queue counted from the location of the queue counter on a link upstream to the final vehicle that is in queue condition. Queue length is measured in units of length (in feet) not in number of cars. Figure 12 presents the maximum queue lengths computed for scenario 1 and Table 10 shows the rates of change in maximum side street queue length for scenario 1. For scenario 1 the change of queue length appears to be relatively small ranging from a 4.5% increase to a 7.3% decrease. The t-test shows that the differences are not statistically significant. The maximum queue lengths for scenario 2 are presented in Figure 13 and their maximum values and rates of change appear in Table 11. For scenario 2 the change fluctuates from a 19.7% increase to a 2.1% decrease. The t-test here also shows that the difference is not significant.

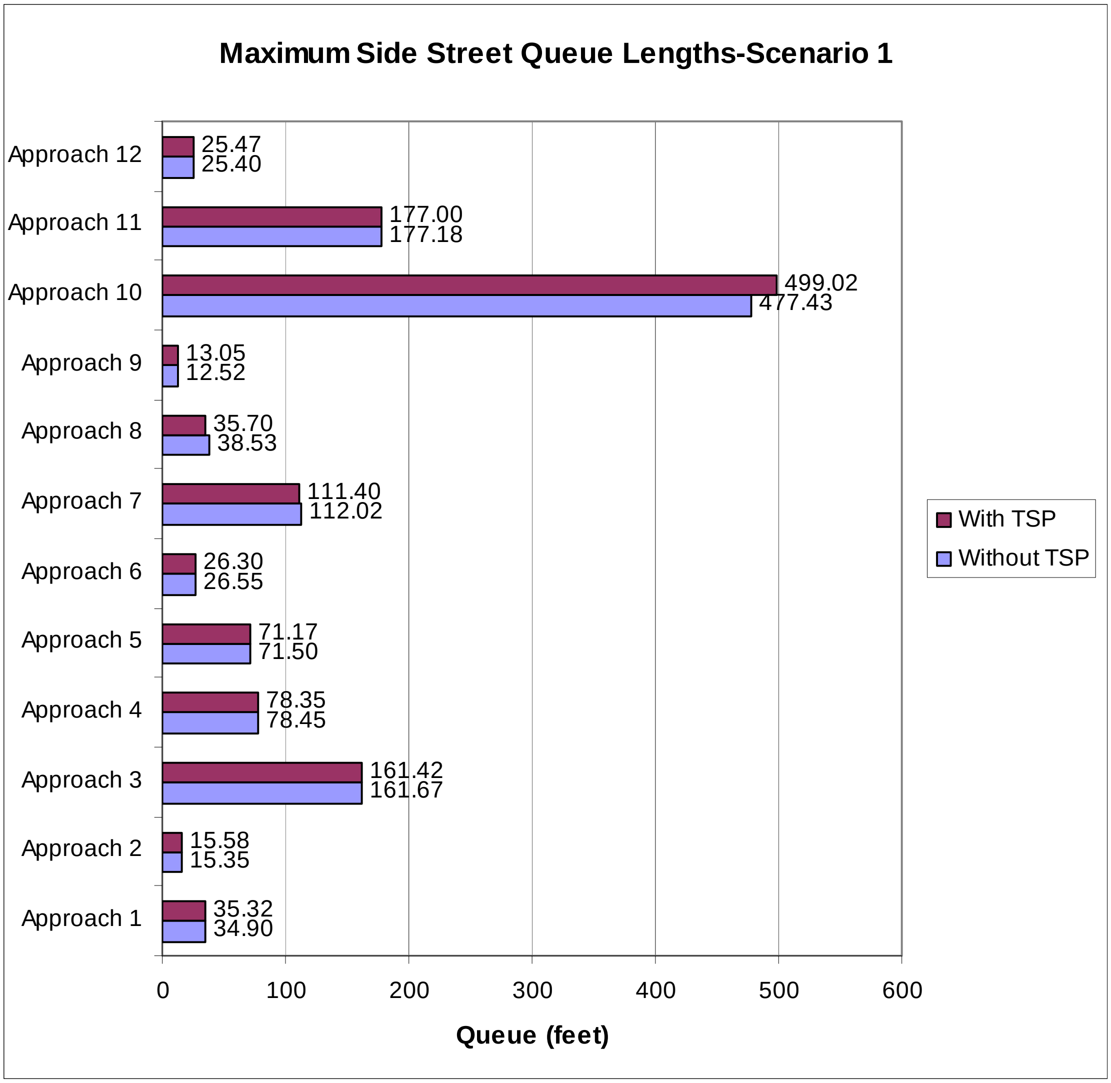


FIGURE 12 Maximum Side Street Queue Length (in feet) for Scenario 1

TABLE 10 Rates of Change in Maximum Side Street Queue Length (in feet) for Scenario 1

	Max Queue (ft) Scenario 1		
	Without TSP	**With TSP**	**Rate of Change**
Approach 1	34.90	35.32	1.20%
Approach 2	15.35	15.58	1.50%
Approach 3	161.67	161.42	-0.15%
Approach 4	78.45	78.35	-0.13%
Approach 5	71.50	71.17	-0.46%
Approach 6	26.55	26.30	-0.94%
Approach 7	112.02	111.40	-0.55%
Approach 8	38.53	35.70	-7.34%
Approach 9	12.52	13.05	4.23%
Approach 10	477.43	499.02	4.52%
Approach 11	177.18	177.00	-0.10%
Approach 12	25.40	25.47	0.28%

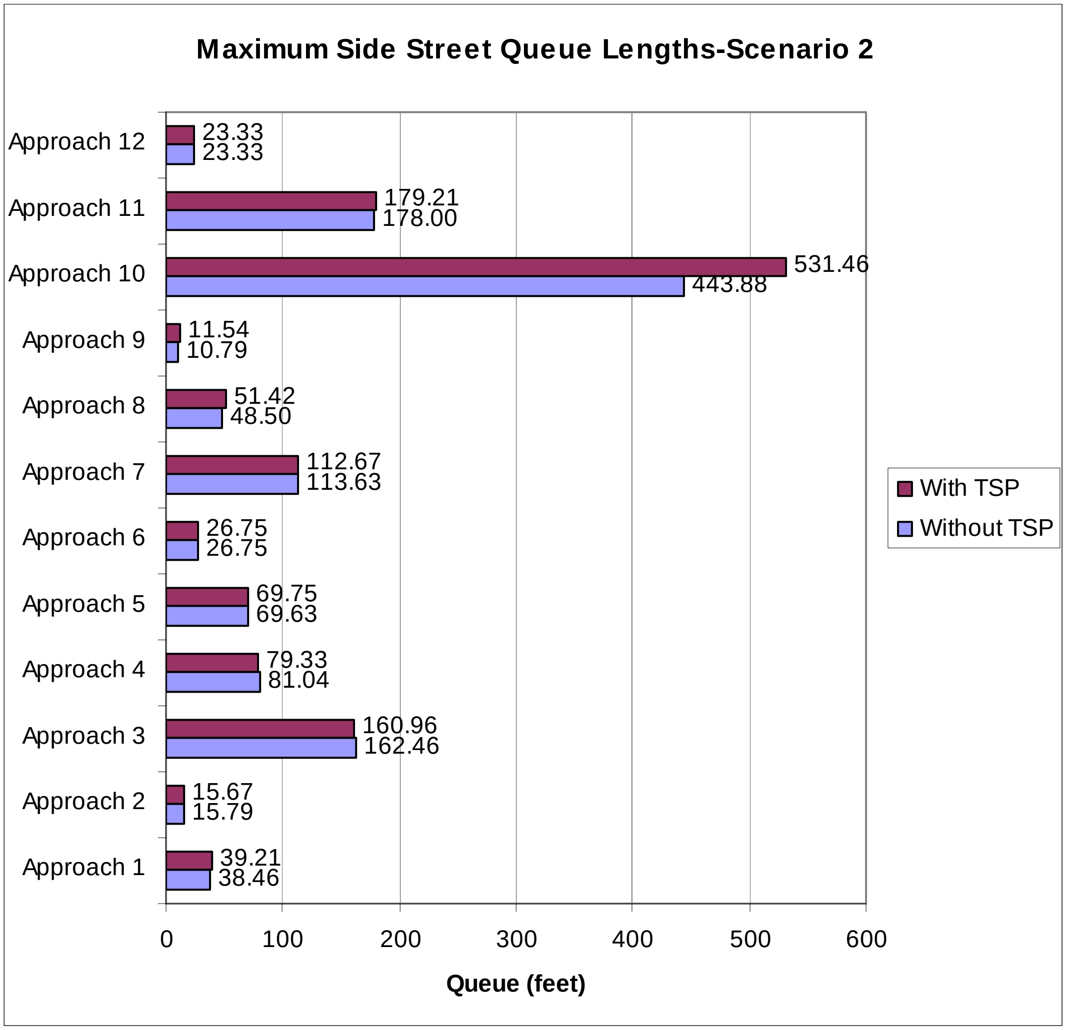


FIGURE 13 Maximum Side Street Queue Length (in feet) for Scenario 2

TABLE 11 Rates of Change in Maximum Side Street Queue Length (in feet) for Scenario 2

	Max Queue (ft) Scenario 2		
	Without TSP	With TSP	Rate of Change
Approach 1	38.46	39.21	1.95%
Approach 2	15.79	15.67	-0.76%
Approach 3	162.46	160.96	-0.92%
Approach 4	81.04	79.33	-2.11%
Approach 5	69.63	69.75	0.17%
Approach 6	26.75	26.75	0.00%
Approach 7	113.63	112.67	-0.84%
Approach 8	48.50	51.42	6.02%
Approach 9	10.79	11.54	6.95%
Approach 10	443.88	531.46	19.73%
Approach 11	178.00	179.21	0.68%
Approach 12	23.33	23.33	0.00%

Summary of Results

The results of the Route 15 simulation analyses are summarized in Table 12 and 13. Based on these results, the following conclusions can be drawn:

- A ten second green extension may reduce bus travel time along Route 15 from 4.6% to 5.8%.
- A ten second green extension may also reduce bus delay along Route 15 from 14.2% to 16.5%.
- A ten second extension may also reduce bus waiting time ranging from 27.3% to 27.9%.
- The other vehicular traffic that moves in the same direction as the buses may also experience travel time savings from 0.3% to 6.3% and a reduction in delay from 1.1% to 9.5%.
- These reductions in bus travel time, bus delay, and bus waiting time may occur without adversely affecting other traffic.

TABLE 12 Summarized Results

	Scenario 1			Scenario 2		
MOE	**Without TSP**	**With TSP**	**Rate of Change**	**Without TSP**	**With TSP**	**Rate of Change**
Bus Travel Time	828.44	790.35	-4.60%	836.76	788.49	-5.77%
Car Travel Time	538.08	536.59	-0.28%	586.56	549.35	-6.34%
Bus Delay	268.09	229.92	-14.24%	295.61	246.73	-16.54%
Car Delay	304.08	300.64	-1.13%	352.96	319.48	-9.49%
Bus Waiting Time-Outbound Line	31.55	35.45	12.36%	29.28	30.48	4.10%
Bus Waiting Time-Inbound Line	129.03	93.10	-27.85%	121.22	88.13	-27.30%

Using VISSIM to Model Transit Priority Strategies along the Old North Route

An initial step taken as part of the VISSIM simulation analyses along The Old North Route 15 was to import Synchro files and other data collected as part of this project into VISSIM. For the purposes of this research the AM Peak was chosen as the analysis period, the Synchro network for which is shown in Figure 14. Another major source of information was the bus schedule for service along the Old North Route. The resulting VISSIM network is presented in Figure 15.

For the purpose of this research two transit priority scenarios along the Old North Route were evaluated. One included a ten second green extension for the AM buses traveling around the entire loop under existing schedules. In the second scenario it was assumed that all bus stops of the nearside type would be relocated to the farside, reflecting the notion that farside stop locations may reduce travel time. Two evaluation measures were employed in this simulation analysis: 1) **travel time** for the bus; and 2) **delay** to non-transit vehicles.

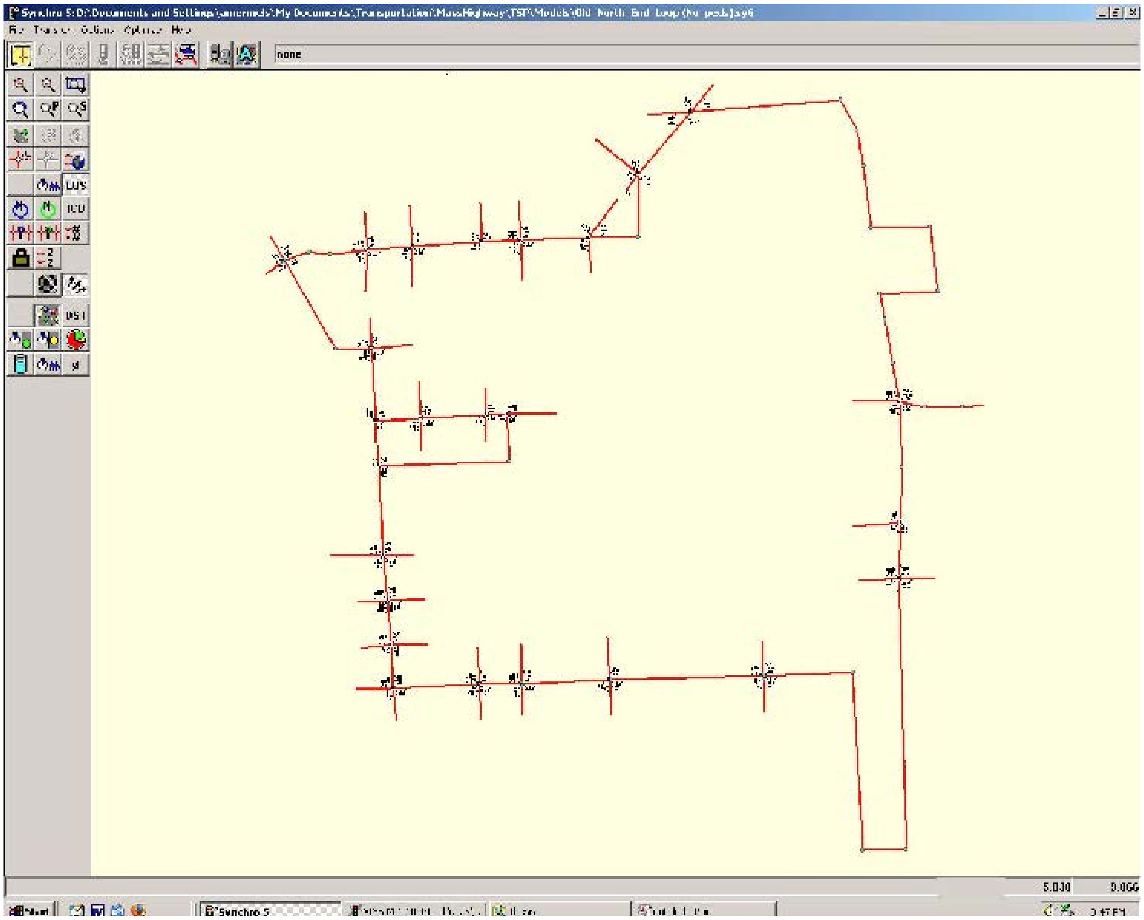


FIGURE 14 Old North Route Synchro Network

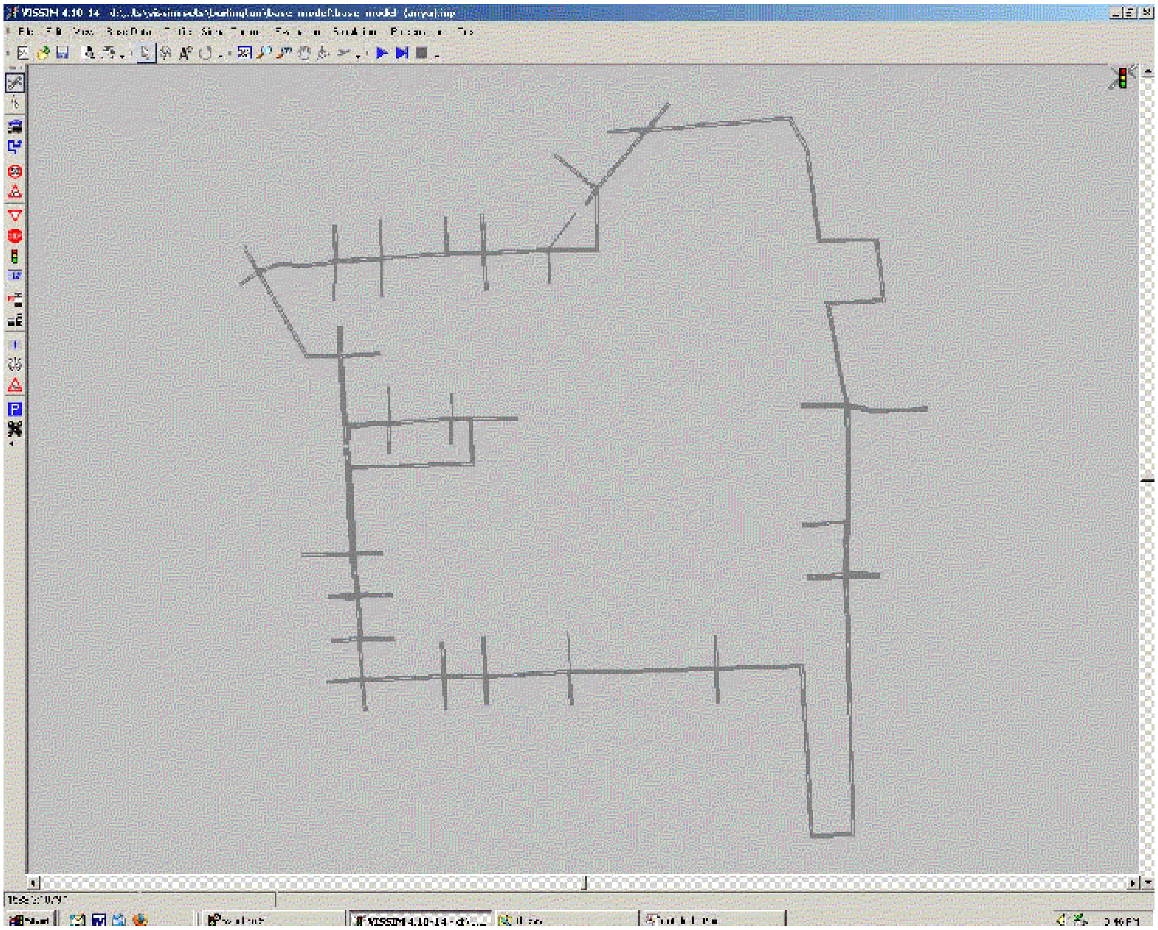


FIGURE 15 VISSIM Network

Simulation Results

The average values for each evaluation measure were calculated based on twenty runs for each scenario. A statistical analysis using the Student's t test was also used to examine statistical significance. The results of the simulation analyses are summarized below. Further details are contained in Mermelstein (11).

Travel Time

Travel time as it is defined in the VISSIM Manual (10), is measured in seconds and represents the time a vehicle crosses the first cross section (start) of the network to crossing the second cross section (destination) and includes waiting or dwell times.

Bus Travel Time

Figure 16 presents the average values of bus travel times to traverse the entire bus route in the base (no priority) and the two scenarios. Table 13 depicts the percent changes in bus travel time in each scenario as compared to the base case. As can be observed, scenario 1 shows a 7% of travel time reduction as compared to the base case and scenario 2 shows a 2.6% reduction as compared to scenario 1. The t-test analysis revealed that average travel times for Base and Scenario 1 are significantly different from each other while the t-test did not show a statistically significant difference between travel times for scenario 1 and 2.

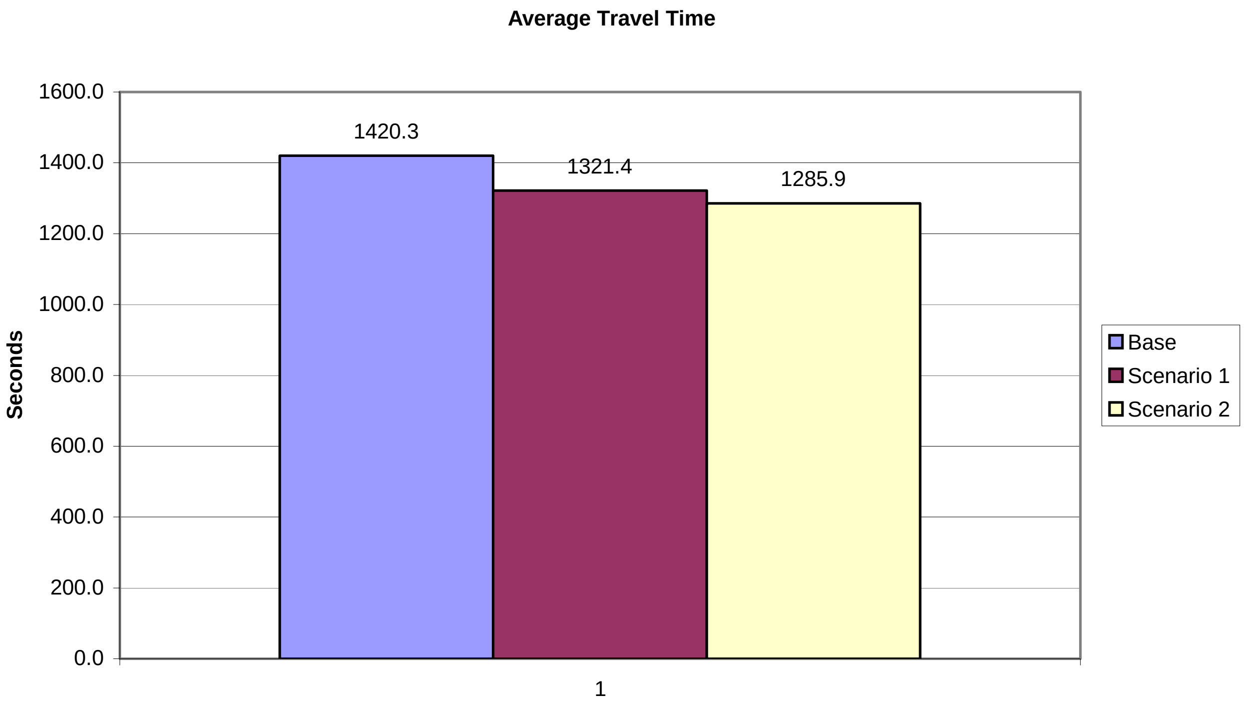


FIGURE 16 Average Bus Travel Times along Old North Route

TABLE 13 Rates of Change in Bus Travel Times along the Old North Route

Bus Travel Time (seconds)		
Base scenario	**Scenario 1**	**Percent Change**
1420.3	1321.4	7.0%
Scenario 1	**Scenario 2**	
1321.4	1285.9	2.6%

Delay to Non Transit Vehicles

As defined in the VISSIM Manual (10), the average total delay per vehicle, measured in seconds, is computed for every vehicle completing the travel time section by subtracting the theoretical (ideal) travel time from the real travel time. The theoretical travel time is the time that would be reached if there were no other vehicles and no signal controls or other stops in the network (reduced speed areas are taken into account). The delay does not include passenger stop times at transit stops. However, the loss time caused by acceleration or deceleration because of such a stop remains part of the delay time.

Figure 17 compares the average values of total delay for each scenario and the base case. Table 14 depicts the corresponding percent changes of total delay. There is a 0.6 % decrease of total delay for other vehicles for Scenario 1 as compared to Base Scenario. There is a 0.7 % decrease of total delay for other vehicles when comparing Scenario 1 and Scenario 2. Based on the t-test, the differences in delays to non-transit vehicles in the base case versus scenario 1 and scenario 2 versus scenario 1 were not statistically significant.

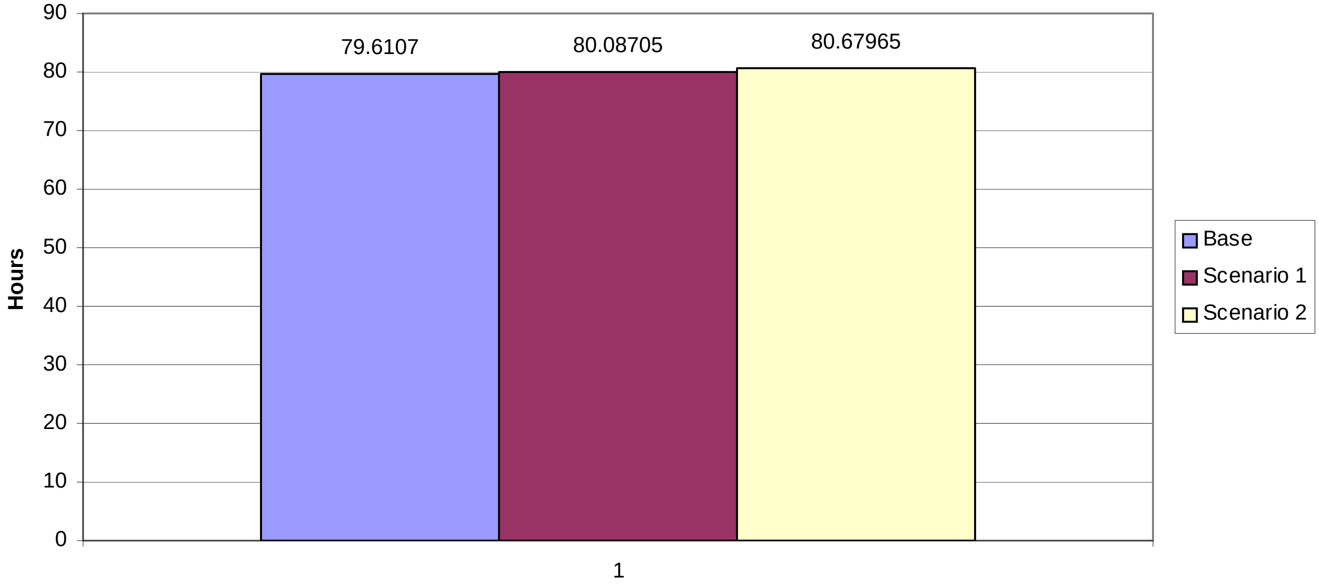


FIGURE 17 Average Total Delay Incurred by Non-transit Vehicles

TABLE 14 Analysis of Total Delay Incurred by Non-transit Vehicles

Average Vehicle Delay (hours)			
Base scenario	**Scenario 1**	**Percent Change**	
79.61	80.09	-0.6%	
Scenario 1	**Scenario 2**		
80.09	80.68	-0.7%	

Summary of Results of Old North Loop Simulation Analyses

The results of the Old North Loop simulation analyses are summarized as follows

- A ten second green extension may reduce bus travel time along the Old North Route by up to 7%.
- A ten second green extension coupled with the relocation of all nearside bus stops to the far side suggests that travel time may diminish although the results did not prove to be statistically significant.

Overall Conclusions and Recommendations

Preliminary conclusions drawn from the simulation analyses are:

- The major results suggest that transit priority may aid in improving overall bus travel time along Route 15 and the Old North Loop and that these results are generally consistent with the results reported in other transit signal priority simulation analyses as well as before and after field studies.
- There is no significant evidence that the ten second green extension along Route 15 creates added waiting time delay to the buses that move along the opposite direction and do not get priority.
- There is no significant evidence that the ten second green extension along Route 15 and the Old North Loop increases delay for the non-transit traffic along the side streets off Route 15 and the overall traffic on the Old North Loop.

Recommendations for future research and deployment:

- Carry out additional simulation analyses considering longer green extensions and couple these analyses with a small scale field study using the evaluation plan presented in the results of Task 3.
- Perform the same the simulation results and the field study for the afternoon peak.
- Consider in future simulation analyses other priority strategies such as a green extension combined with red truncation and early green intervals with queue jumps.

- Perform as part of future simulation analyses sensitivity analyses considering different bus headways, bus stop types and locations, and fare collection methods.
- Monitor and evaluate transit priority strategies deployed on a long term basis in order to identify necessary modifications required as traffic patterns and transit policies change over time.

Task 3 – Conduct a Field Test

It was decided that a field test would not be carried out due to the fact that the planned investment in transit priority equipment was postponed to Fiscal Year 2008. However, in anticipation of the conduct of a field test in the future, an evaluation plan was designed and is presented below. Included in the plan is a proposed set of evaluation objectives and measures.

Evaluation Plan

The development of the evaluation plan should consider the interests and objectives of the stakeholders and the operational environments in which a transit priority strategy is being considered for deployment in the Chittenden County area. As reflected in the results of Task 1b, objectives may be to improve bus schedule adherence and overall bus service quality while at the same time not negatively impact non-transit traffic. Operational environments may include suburban bus service, downtown bus service, or some form of paratransit van services. In addition to the stakeholders and operational environments, two other important elements to consider in the development of an evaluation plan, as depicted in Figure 18, are the transit priority strategies being considered and the measures to use to evaluate the performance of each strategy. As mentioned in the results of Sub-Task 1a, the strategies may include a simple green extension or may include a green extension and a red truncation.

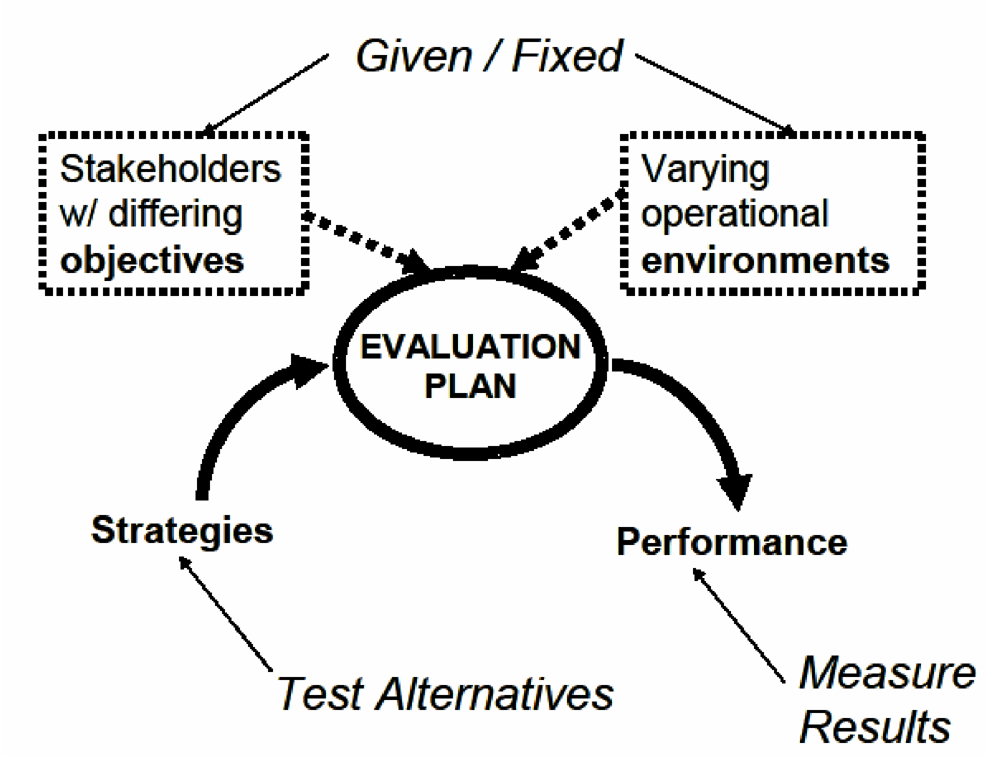


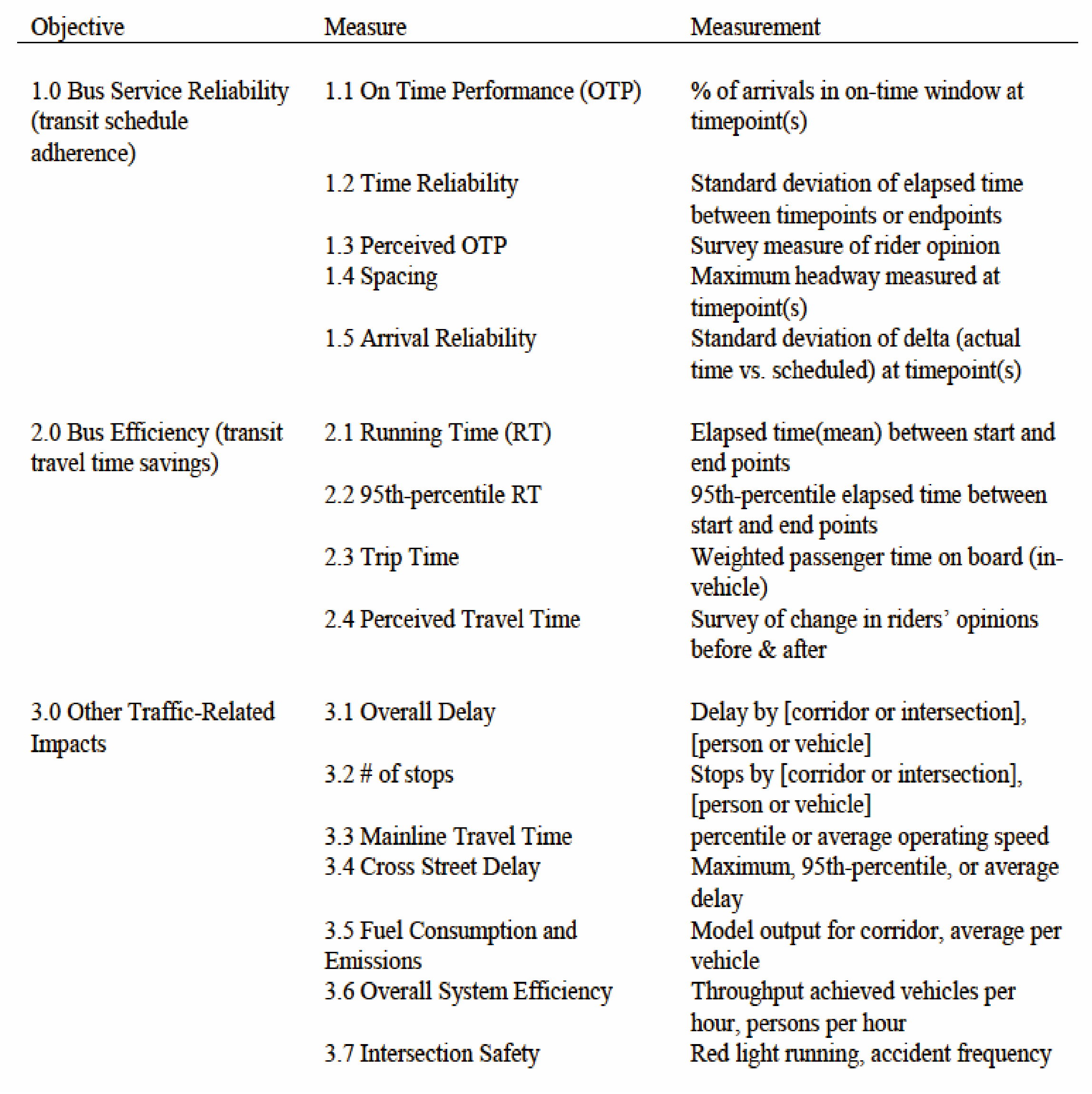
FIGURE 18 Evaluation Plan

Evaluation Objectives and Measures

Table 15 presents a set of transit priority objectives that might be considered by the CCMPO, the CCTA, and other stakeholders in the development of the evaluation plan to assess transit priority strategies as part of a field test in the Chittenden County area. These objectives relate to bus service reliability, bus efficiency, and other traffic related impacts. (9)

The bus service reliability objectives relate to the potential of transit priority to improve bus schedule adherence. Bus efficiency objectives try to capture the effects of transit priority in terms of reductions in bus delay and operating cost. Finally, the other traffic-related impact objectives attempt to address impacts on non-transit traffic and other issues including safety and air quality and to establish a relationship between the implementation of transit priority and the operation of the non-transit traffic of the study network. It evaluates how transit priority implementation can positively or negatively impact other traffic. Along with these proposed objectives are various measures of effectiveness, and relevant measurement techniques for each measure of effectiveness.

TABLE 15 A Proposed Set of Evaluation Objectives, Measures, and Measurement Techniques



Objective	Measure	Measurement
1.0 Bus Service Reliability (transit schedule adherence)	1.1 On Time Performance (OTP)	% of arrivals in on-time window at timepoint(s)
	1.2 Time Reliability	Standard deviation of elapsed time between timepoints or endpoints
	1.3 Perceived OTP	Survey measure of rider opinion
	1.4 Spacing	Maximum headway measured at timepoint(s)
	1.5 Arrival Reliability	Standard deviation of delta (actual time vs. scheduled) at timepoint(s)
2.0 Bus Efficiency (transit travel time savings)	2.1 Running Time (RT)	Elapsed time(mean) between start and end points
	2.2 95th-percentile RT	95th-percentile elapsed time between start and end points
	2.3 Trip Time	Weighted passenger time on board (in-vehicle)
	2.4 Perceived Travel Time	Survey of change in riders' opinions before & after
3.0 Other Traffic-Related Impacts	3.1 Overall Delay	Delay by [corridor or intersection], [person or vehicle]
	3.2 # of stops	Stops by [corridor or intersection], [person or vehicle]
	3.3 Mainline Travel Time	percentile or average operating speed
	3.4 Cross Street Delay	Maximum, 95th-percentile, or average delay
	3.5 Fuel Consumption and Emissions	Model output for corridor, average per vehicle
	3.6 Overall System Efficiency	Throughput achieved vehicles per hour, persons per hour
	3.7 Intersection Safety	Red light running, accident frequency

Task 4 – Develop a Set of Guidelines

Task 4 includes the development of a set of guidelines to assist VTrans staff and public officials in the Chittenden County area in the planning and deployment of transit priority strategies. As described in Task 1, transit priority is a form of traffic signal control strategy provided to facilitate the flow and passage of transit buses. Transit priority requests are often conditional and may, for example, be granted on one or more conditions such as the absence of a pedestrian phase, the presence of a green interval, and a prescribed level of bus occupancy or degree of bus lateness. The guidelines are divided into two sections: 1) Planning, and 2) Deployment. These guidelines should be of interest to State and local traffic engineers and public transit planners and operators in Chittenden County who are contemplating the implementation of a transit priority strategy.

Planning

Institutional Issues, Local Needs Assessment, and System Objectives and Requirements

Planning for a transit priority system is not a trivial task. A variety of institutional issues and local concerns must be addressed ranging from the integration of transit priority into existing and potentially incompatible, emergency vehicle preemption systems to the identification of the important stakeholders, to the assessment of priority system needs and the formulation of local transit priority objectives and requirements (5, 12). These objectives and requirements provide the basis for an evaluation of transit priority strategies using either simulation models or field tests

Pre-Deployment Impact Analysis

As part of planning, VTrans, CCMPO and other stakeholders should take steps to ensure that a local impact analysis is conducted to assess the anticipated consequences of alternative transit priority strategies under consideration. Among those consequences may be the impact on transit schedule adherence as well as impacts on traffic flow and vehicular and pedestrian safety. This local impact analysis may include field tests and/or the use of microscopic simulation analysis as performed in Task 2 of this project.

Based on a review of literature in Sub-Task 1a, the impacts of transit priority have been shown to have both positive and negative impacts in more than two dozen actual transit priority deployment projects in the U.S. and abroad. Moreover, simulation analyses reported in the literature review have produced results generally consistent with the impacts actually experienced in the project deployments. An overall observation made based on the review of field tests and full scale deployments carried out by others is that transit priority strategies can be integrated into conventional traffic signal control systems in an appropriate and desirable manner, provided that such integration is done with caution, that anticipated impacts are considered, and that the transit priority system and equipment are designed and installed properly. Major impacts to be considered relate to overall traffic flow and pedestrian safety as discussed below.

Traffic Flow

There is significant evidence as reported in Task 1a that the implementation of transit priority strategies may reduce travel times for transit vehicles. However, another expected impact may be delay to all other vehicles. To illustrate the level of magnitude of these impacts, a summary of past and on-going research on transit priority is provided below.

Most transit priority projects have only been deployed in the U.S. within the past 8 to 9 years and results from operational field test evaluations and simulation analyses are difficult to compare across the board because performance measures are not well defined in a standardized framework. Moreover, different transit priority strategies including green extensions only and green extension in combination with red truncation and other tactics yield different impacts. As reported in Sub-task 1b, experience from a number of transit priority projects in the U.S. and abroad suggests that transit priority may, depending on the strategy employed and other factors reduce transit travel times 6% to more than 40% with little or no negative impacts on non-transit travel time, if properly deployed.

It should also be stressed that traffic simulation models may be a cost effective means to analyze the impact of transit priority on traffic flow. As part of this research project, the VISSIM simulation model was used to assess impacts of a green extension only strategy on both transit and non-transit vehicles. Results indicated that bus service reliability could be improved, travel time would possibly diminish, and non-transit vehicle delay would likely be minimal. It should also be pointed out that the transit priority strategy might have a varying level of impact on transit and other vehicles. A green time extension has also been determined by others to provide benefits to buses with no travel time impact to other users (8). However, a green extension in combination with red truncation (i.e. recall) may negatively impact non-transit vehicles, depending on the frequency of bus service. It is further recommended that a strategy consider the specific conditions that influence the corridor or area of interest. These conditions may include: frequency and direction of travel for vehicles requesting priority, roadway characteristics, travel demand, presence and frequency of pedestrian phases, transition strategy, cycle characteristics, and intersection spacing and progression strategy (13). The use of different types of priority such as queue jumping and phase re-servicing in addition to green extension may be necessary to match the status of the intersection in order not to affect signal coordination (14).

Safety for Pedestrians

Pedestrian accidents with motor vehicles represent a serious safety problem. Pedestrian fatalities typically account for more than 10% of the motor vehicle deaths nationwide annually. In terms of accident locations, approximately one-third of accidents involving pedestrians have occurred at intersections (15). It is suggested that a safety audit be conducted during the planning of transit priority systems especially at locations near college campuses and in downtown Burlington areas.

This audit should review the potential impacts transit priority strategies might have on pedestrian safety. This audit should review the historical accident data within the area of interest; the length of pedestrian cycles based on the age and other demographics of the local population; the location of residential housing and retail activities; location and placements of bus stops; pull off areas; and distance between bus stop locations.

Economic Analysis

It is strongly recommended that an economic analysis be performed prior to transit priority deployment to identify and estimate the fixed and recurring costs associated with priority investments. Recurring costs should include, for example, costs of an equipment maintenance agreement as described below. ITS projects such as transit priority may typically have a short service life, lower upfront investment costs, and higher operating costs than traditional physical infrastructure projects. Since the cash flow profile of ITS and traditional investments are radically different and the time value of money for ITS investments may not be that important, it has been argued that traditional benefit-cost analysis may not be appropriate and a multi criteria analysis approach should be used (16). It is suggested that life cycle cost analysis be employed and an attempt be made to look at all life cycle capital and operational costs within a larger economic analysis framework.

Financing

A financial plan for transit priority system deployment needs to be developed. This plan will identify funding sources to support capital investments and to defray operating and maintenance costs. Funding is available from Federal, state, and local sources such as Congestion Management and Air Quality (CMQP) and other programs in the SAFETEALU Act of 2006. It should also be stressed that such public funding sources may include transportation agencies as well as local fire and rescue departments.

Deployment

Procurement

While it has been suggested that transit priority systems can be procured using standard procurement processes, there are special considerations that need to be taken into account. Lessons learned from past ITS procurements and procurement experiences were used to provide insights into the identification of system objectives and requirements and preparation of requests for proposals and proposal evaluation.

Identification of Systems Objectives and Requirements

The procurement process begins with the identification of project objectives and requirements. As mentioned above, a clear understanding of the project scope of work objective is required of all stakeholders and participants to manage expectations and to preclude misunderstanding later in the process. Technological limitations must also be understood. A common frame of reference and a common definition of terms will need to be developed and adhered to. The proposed system objectives and requirements will then be translated into technical and operational requirements for venders to develop into a fully functional system. Sound technical specifications are a prerequisite for success. Vaguely defined requirements will result in confusion and will necessitate negotiation with the contractor to settle differences.

RFP Preparation/Proposal Evaluation

A Request for Proposals (RFP) defines the project scope of work and system objectives and requirements, provides the technical and operational performance requirements, outlines the compliance requirements, and defines the performance period. It is suggested that a single integrator be responsible for design, procurement of components, system integration, installation, testing of the project, and user training.

Pre-Installation Site Survey

A pre-installation survey by the contractor(s) is highly recommended. As part of this on-site survey, the contractor should determine the impact of roadway geometry, bus stop placements, line of sight restrictions, pedestrian crossing volumes, and existing equipment to the system design. In addition, detector placement must be carefully sited to avoid putting a bus in the dilemma-zone when the traffic signal turns amber. Detector placement and installation will need to consider the impacts of bus speed, length of green extension, and intersection width as well as location of bus stops. For example, for a bus traveling at 15 mph (22 fps) with a maximum green extension of 10 seconds through an intersection width of 40 feet, a detection distance of approximately 180 feet provides sufficient time to allow the bus to clear the dilemma zone.

System Installation

The typical priority system has three major subsystem components, including the in-vehicle subsystems, road-side subsystems, and center subsystems. Each subsystem has its own installation challenges. In-vehicle subsystems consist of those component parts of the system that are installed on the vehicle. For example, a simple priority system may consist of the emitter, its power system and its microprocessor system. More complex systems may include a vehicle location device such as a global positioning system (GPS) locator and automatic passenger counters (APCs). Road-side subsystems are those parts of the system that reside outside the designated vehicles. Typically, they would include detectors mounted in the vicinity of the traffic signals and power sources that service the detectors, microprocessors and communications equipment collocated with the traffic signal controller boxes. Center subsystems are those items of equipment that must interface with the central traffic signal management system and the transit management system.

It is recommended that the contractor be responsible for quality control throughout the installation process. The contractor should be required to provide installation drawings for approval. In addition, the contractor should be required to present a prototype installation of every subsystem and complete operational testing of all prototype installations. The contractor should also provide for review of site-specific installation specifications tailored to the physical characteristics of each site.

Evaluation

System evaluations during deployment provide a means to assess whether a priority system meets its intended objectives. The evaluation process should consist of the following elements: (1) an evaluation frame of reference, (2) evaluation planning, (3) evaluation implementation, and (4) potential evaluation spin-offs (17).

The evaluation frame of reference provides a context for the evaluation. It defines the project objectives, external influences, local issues, and site characteristics. As described in Task 3, the evaluation plan outlines what should be measured (the impacts) and how impacts might be measured (measurement techniques). Evaluation implementation outlines evaluation plan execution, data collection, and analysis. For additional guidance on the design of ITS project evaluations, see the U.S. DOT's Joint Program Office website (18).

A major product of the evaluation is an assessment of system objectives and impacts, including benefits, costs, and other consequences. Transit priority system objectives may relate to transit service reliability, efficiency and other traffic impacts. In addition, the priority system evaluation should consider assessing broader impacts related to interoperability, maintainability, reliability, expandability, affordability, institutional and organizational issues, and human factors.

Finally, it should be stressed that continuous evaluations should be conducted as soon as possible during deployment. Evaluations provide a means to measure the performance of the system against the measures used and the results supply agencies in other metropolitan areas with useful information regarding deployment results, challenges, and lessons learned.

Summary, Conclusions and Recommendations

Innovations in traffic signal technology and other factors have increased the interest in transit signal priority in the Chittenden County area. The primary goal of this project is to assist the Vermont Agency on Transportation (VAOT), regional agencies, and local jurisdictions in the State in considering the use of traffic signal systems and technologies to implement traffic signal priority strategies for buses. The study includes an evaluation of the impacts, merits and limitations associated with alternative traffic signal priority strategies and a review of the lessons learned in communities similar to those in Vermont where such strategies have been deployed. An underlying aim of the project is to assist VAOT and other public agencies in the State in planning and deploying signal priority strategies for transit buses in concert with other preferential signal treatments such as traffic signal preemption strategies currently in place and being planned for fire and rescue services. The coordination of traffic signal priority and preemption strategies for multiple types of vehicles is of utmost importance to preserve safety, facilitate emergency response, enhance traffic flow, and improve overall mobility.

Major conclusions of this study are:

- Results of transit priority system deployments in the U.S. and abroad reviewed in Task 1 suggest that transit priority in small, medium, and large urban areas may reduce transit travel time and may lead to improvements in transit schedule adherence and other aspects of transit performance without major negative impacts on overall traffic flow.

- Migrating to a single transit signal priority and emergency preemption system as a long range plan is an admirable goal on the part of officials in Chittenden County Region and to operate with the two existing systems in an "unencoded" manner is a reasonable step to take unless abuse by authorized users takes place or other problems arise.
- The results of the preliminary simulation analyses conducted in Task 2 suggest that transit priority may aid in improving overall bus travel time along Route 15 and the Old North Loop and that these results are generally consistent with the results reported in other transit signal priority simulation analyses as well as before and after field studies as reported in the literature review in Task 1. In addition, the simulation analyses suggest that there is no significant evidence that the ten second green extension increases delay for the non-transit traffic along the streets intersecting Route 15 and the overall traffic on the Old North Loop.
- The guidelines developed as part of Task 4 should be considered by VAOT, local jurisdictions, transportation agencies, and public safety agencies in the planning and design of transit priority strategies and treatments along signalized arterials in the State.

Recommendations for future research:

- Carry out additional simulation analyses considering other priority strategies including longer green extensions and multiple AM, PM, and mid-day peak analysis periods. As part of future simulation analyses, sensitivity analyses should be included considering different bus headways, bus stop types and locations, and fare collection methods.
- Conduct a small scale transit priority field test in conjunction with the additional simulation analyses. As part of the field test, a set of transit priority objectives and evaluation criteria should be used to assess the performance of the priority system. These objectives and criteria should relate to bus service reliability, bus efficiency, and other impacts on non-transit traffic and overall traffic flow as presented in Task 3.

As part of a transit priority field test it is recommended that serious consideration be given to hiring a contractor (e.g. the system/equipment vendor or a third party) to be responsible for quality control throughout the system installation process. Because of the limited number of full time signal technician staff in the Burlington area, contracting out this quality control function may be essential depending on the workload of the local signal technicians. As indicated earlier, consideration should also be given to the need to prepare roadside equipment installation drawings especially when excavation is required. In addition, the contractor should be required to present a prototype installation of each subsystem including roadside and in-vehicle components and complete operational testing of all prototype components as necessary. Finally, a maintenance agreement with a contractor should be established to deal with system/equipment challenges and malfunctions (if any) during the field test period.

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Appendix A. Transit Priority Stakeholders

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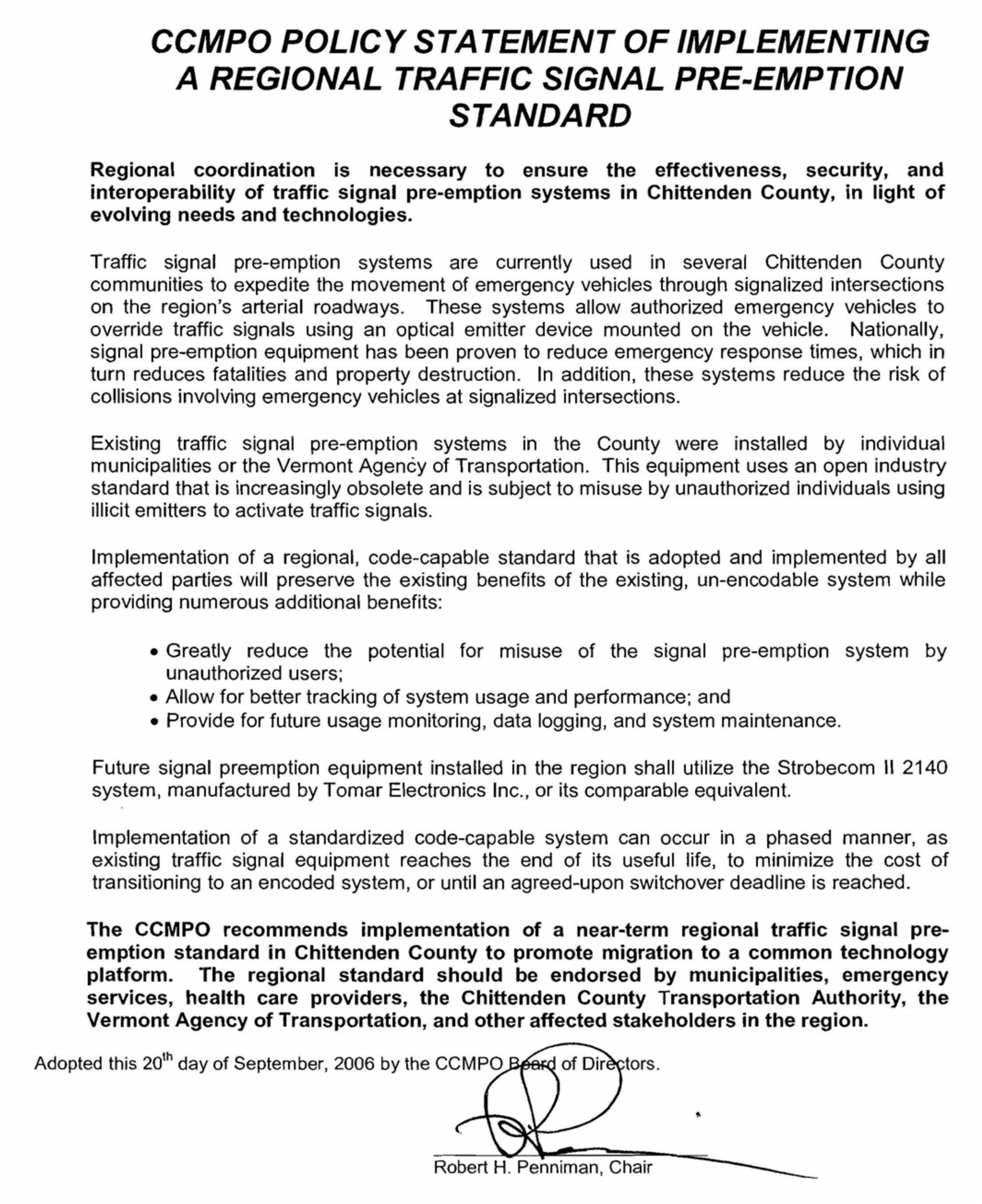
Appendix B. CCMPO Traffic Signal Preemption Policy



CCMPO POLICY STATEMENT OF IMPLEMENTING A REGIONAL TRAFFIC SIGNAL PRE-EMPTION STANDARD

Regional coordination is necessary to ensure the effectiveness, security, and interoperability of traffic signal pre-emption systems in Chittenden County, in light of evolving needs and technologies.

Traffic signal pre-emption systems are currently used in several Chittenden County communities to expedite the movement of emergency vehicles through signalized intersections on the region's arterial roadways. These systems allow authorized emergency vehicles to override traffic signals using an optical emitter device mounted on the vehicle. Nationally, signal pre-emption equipment has been proven to reduce emergency response times, which in turn reduces fatalities and property destruction. In addition, these systems reduce the risk of collisions involving emergency vehicles at signalized intersections.

Existing traffic signal pre-emption systems in the County were installed by individual municipalities or the Vermont Agency of Transportation. This equipment uses an open industry standard that is increasingly obsolete and is subject to misuse by unauthorized individuals using illicit emitters to activate traffic signals.

Implementation of a regional, code-capable standard that is adopted and implemented by all affected parties will preserve the existing benefits of the existing, un-encodable system while providing numerous additional benefits:

- Greatly reduce the potential for misuse of the signal pre-emption system by unauthorized users;
- Allow for better tracking of system usage and performance; and
- Provide for future usage monitoring, data logging, and system maintenance.

Future signal preemption equipment installed in the region shall utilize the Strobecom II 2140 system, manufactured by Tomar Electronics Inc., or its comparable equivalent.

Implementation of a standardized code-capable system can occur in a phased manner, as existing traffic signal equipment reaches the end of its useful life, to minimize the cost of transitioning to an encoded system, or until an agreed-upon switchover deadline is reached.

The CCMPO recommends implementation of a near-term regional traffic signal pre-emption standard in Chittenden County to promote migration to a common technology platform. The regional standard should be endorsed by municipalities, emergency services, health care providers, the Chittenden County Transportation Authority, the Vermont Agency of Transportation, and other affected stakeholders in the region.

Adopted this 20th day of September, 2006 by the CCMPO Board of Directors.

Robert H. Penniman, Chair

Appendix C: Intersections at which 3M and Tomar Systems are Located

City	Intersection	System
Burlington	North Street & Park Street	Tomar 2080
Burlington	Park Street & Sherman	Tomar 2080
Burlington	North Street & North Avenue	Tomar 2080
Burlington	North Street & N. Champlain	Tomar 2080
Burlington	North Street & Intervale/Elmwood	Tomar 2080
Burlington	North Street & N. Winooski Avenue	Tomar 2080
Colchester	Route 2/7 & Blakely Road (Rt. 127)	Tomar 2140
Williston	Marshall & S. Brownell	Tomar 2080
Williston	Route 2 & 2A	Tomar 2080
Williston	Route 2 & Boxwood	Tomar 2080
Williston	Route 2 & Maple Tree Place	Tomar 2080
Williston	Route 2A & Marshall	Tomar 2080
Williston	Marshall & Harvest Lane/4-Seasons	Tomar 2140
Williston	Marshall & Harvest Lane	Tomar 2140
Williston	Marshall & Brownell	Tomar 2080
Williston	Route 2A & Connor Way	Tomar 2080
Williston	Route 2A & I-89 Northbound Ramps	Tomar 2080
Williston	Route 2A & I-89 Southbound Ramps	Tomar 2080
S. Burlington	Swift & Farrell	Tomar 2080
S. Burlington	Dorsett & Kennedy	Opticom 262
S. Burlington	Dorsett & Library/Educational Ctr.	Opticom 262
S. Burlington	Dorsett & San Remo/Hawthorne Suit	Opticom 262
S. Burlington	Dorsett & University Mall	Opticom 262
S. Burlington	Dorsett & Blue Mall	Opticom 262
S. Burlington	Dorsett & Market St./University Mall	Opticom 262
S. Burlington	Dorsett & Barnes& Noble/Chittenden	Opticom 262
S. Burlington	Dorsett & Williston Road	Opticom 262
S. Burlington	Williston Road & Hinesburg Road	Opticom 262
S. Burlington	Williston Road & Kennedy Drive	Opticom 262