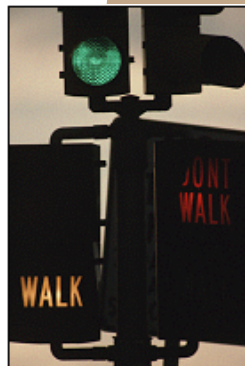


EFFECTIVENESS OF BUS SIGNAL PRIORITY FINAL REPORT

JANUARY 2002



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EXECUTIVE SUMMARY

Effectiveness of Bus Signal Priority (BSP) study was funded by the National Center for Transit Research (NCTR) at the Center for Urban Transportation Research (CUTR). This study evaluates BSP's impact on traffic operations. The goal was to examine how different situations, such as the level of congestion, placement of bus stops, presence of express bus service, and number of transit vehicles on route, require different techniques of BSP such as real-time or fixed-time based control. Those techniques also utilize a variety of different control strategies such as phase suppression, synchronization, compensation, and green recall. In order to guide transportation agencies in this decision-making process, a spreadsheet was developed to help an agency determine if signal priority is viable in a specific corridor. A set of guidelines was then developed to determine the most beneficial method of priority to pursue.

To establish how BSP can be most effective, ten transit professionals (planners and engineers) involved in installing BSP projects were interviewed. Traffic engineers interviewed stated that agencies must develop control strategies that are appropriate for the given intersections in their area. Transit planners interviewed for this study explained that BSP did not create any significant delays to non-transit vehicles. A literature search also uncovered statements on the significant issues of BSP, such as considering the volume of bus passengers, degree of existing congestion level, and delay to non-transit vehicles. The literature search revealed the benefits of direct priority strategy in areas with low congestion and an indirect priority strategy for areas with a high degree of congestion. Agencies utilizing BSP around the country were studied to determine which types of priority are used in certain conditions and what technology is being implemented.

It was determined that an effective bus priority system must ensure transit vehicles in all directions can be assisted without excess delay to non-transit vehicles. BSP offers fewer benefits in areas with extremely high bus volumes or very light traffic. The most appropriate priority method may be one that combines the various elements of existing priority techniques. Real-time control strategy offers the greatest benefits, although any system must be designed with the particular area needs in mind. As a result of the information gathered, a framework for an ideal bus priority system was developed. Based upon that information, the "Pre-Implementation Checklist" was designed. The checklist focuses on the most critical factors in BSP and recommends pursuing BSP if an area has enough characteristics in place to make BSP effective. The "Operational and Design Guidelines" for BSP assist an agency in choosing the most appropriate BSP method that complements the area characteristics.

INTRODUCTION

BSP is being more widely deployed in North America to address traffic congestion, caused by traffic signals, for on-street transit service. Signal priority for transit vehicles is expected to improve transit operations and service quality. In theory, an improvement in transit performance provides additional incentive for people to switch modes and reduce traffic congestion. This has been an issue of debate, both among traffic engineers and transit planners. The traffic engineers' resistance to implementation has often been based on a concern that overall traffic performance may be unduly compromised when signal timing intended to optimize traffic flow is overridden to provide a travel advantage to transit vehicles. For purposes of this report transit signal priority (TSP) will be referred to as bus signal priority (BSP)

This research project evaluates how traffic operations are affected by bus signal priority. The effectiveness of bus signal priority on transit vehicles and the impact on traffic operations are explored. Funding for this study was provided by the National Center for Transit Research (NCTR) at Center for Urban Transportation Research (CUTR). This study also addressed all the implications of BSP thus giving a more objective analysis of the advantages and disadvantages. It attempted to provide missing information to transit planners and traffic engineers across the nation as they become more involved in the deployment of BSP.

TERMINOLOGY

Terminology in this report is based in part on the Sunkari et al (22) study on models to evaluate bus priority.

- Unconditional priority: Priority is given whenever a bus detector requests it from signals.
- Conditional priority: Includes variables that may limit priority given, such as bus occupancy, queue length, and time since last priority was granted.
- Phase: Part of the traffic signal time cycle allocated to any combination of traffic movements receiving right-of-way simultaneously during one or more intervals.
- Green extension: Green phase is extended when bus is nearby to allow it to go through.
- Special phase: A special green phase is injected into the normal phase sequence while all other phases are stopped.

- Red truncation: If the bus arrives at an intersection during the beginning or middle of a red phase, the red phase is truncated and green phase is injected to allow the bus to go through.
- Compensation: Green time is allocated to a non-priority phase that was truncated to make up for lost time.
- Early start: When bus arrives at intersection during a red, green follows quicker than usual.
- Green recall: A green phase is displayed each cycle whether demand exists or not.
- Synchronization: Timing groups of traffic signals along an arterial to provide for the smooth movement of traffic with minimal stops.
- Phase suppression: One or more non-priority phases with low demand may be omitted from the normal phase sequence.

EARLY WORK

The development of Intelligent Transportation System (ITS) technology opened up new possibilities for bus signal priority involving real-time tracking. The theory of bus priority was established with experiments that took place as early as 1962. Many studies and theories were established before the 1990's that laid the groundwork for the bus priority of today. Some of the early work is outlined here to give an idea on how BSP evolved over the last few decades.

In 1978 Vincent et al used a Bus Priority Assessment Simulation (BUSPAS) to test preemption control strategies at an intersection. They found that "green extension only" was of little benefit to buses and caused very minor delays to other traffic. Contrastingly, a "green extension, red truncation, no compensation" control method was of great benefit to buses, yet caused large delays to other traffic. A "green extension, red truncation, compensation" control method gave buses some benefit, without the long delays for other traffic.

In 1981 Jacobson and Sheffi (12) showed how bus priority is made more effective if one can change the underlying signal setting. For example, the benefits of bus priority are small when traffic in a preemption direction is much higher than cross traffic flow. A system complex enough to handle such issues is only now possible with the emergence of ITS technology.

An early bus priority plan was the NW 7th Avenue Bus Priority System in Miami, Florida (16). The testing ran from August 1974 to March 1976. Thirty-seven traffic signals were equipped with optical signal preemption equipment. The system used an intense stroboscopic light that could be

picked up by the receiver at the intersection from approximately 1800 feet. Once a bus was detected the signal was either extended until the bus came through (with obvious adjustments made if the bus was delayed) or the current signal phase was adjusted to include a green phase for the bus to go through.

There was no statistically significant increase in bus accidents and total accident rates of all vehicles on NW 7th Avenue actually decreased. None of the potential safety concerns (two buses preempting the same signal from different directions, bus operators expecting a guaranteed green, auto and pedestrian confusion, automobiles clustering around the bus to get a green signal) materialized during the testing phase (16).

BSP STRATEGIES

Certain signal systems and programs tend to form the backbone of many BSP systems (for example, many are based on the BUS-TRANSYT optimizing program), while many areas choose to put together an original BSP system with completely different hardware, software and purposes. In some cases an agency will choose a vendor to install an entire system; sometimes they will purchase hardware from different suppliers and merely use a vendor's software system; and sometimes an area customizes the control themselves using a variety of different hardware sources. Consequently there are a large number of different "systems" in existence that are entirely unique to that area. Only some of the more popular system vendors are outlined in this section.

To understand the various systems mentioned in this section, the basic priority concepts and the strategies that define and differentiate these concepts are outlined below.

Control Strategies

The four kinds of control strategies for awarding BSP are:

- Real-time: Rely on constantly updated information to make decisions regarding priority. A real-time signal control model is more flexible to changing conditions, hence is generally more effective.

- Fixed-time: Fixed-time control applies a signal control plan based on the average conditions of an area. Fixed-time control does not receive constantly updated information; the best control scheme is applied to the area regardless of actual conditions.

- Schedule-based: Priority is awarded based on the bus schedule. If the bus is running late then it receives priority through intersections. Schedule-based control is more effective at reducing bus travel times. Since schedule-based control does not need information of bus locations it requires less communication equipment, which makes it more cost effective.
- Headway-based: Priority is awarded based on the headway between buses. Buses avoid bunching up with other buses in this control strategy. Headway-based control is more effective at reducing wait times.

On occasion, the terms direct or indirect priority are used. Direct priority provides solutions for a particular bus when it has reached or is very close to an intersection. Indirect priority looks to clear up congested intersections ahead of time so buses can eventually travel through with little or no congestion.

Priority Concepts

The two types of basic bus priority concepts are:

- Active priority: Each bus is detected on approach to an intersection and the signals are then changed. Active systems can be a combination of real or fixed-time control strategies, and schedule or headway-based control strategies. Active concepts are more effective and widely used.
- Passive priority: Traffic control devices are adjusted to suit the bus schedule along the route in general using a combination of fixed-time and schedule-based control strategies. The literature search has indicated that passive priority systems and fixed-time systems are rarely used. In some applications, passive priority is implemented only at certain intersections – primarily it favors roads with significant transit usage, often close to the buses origin point where schedules are most likely to be adhered to – while the entire corridor has an active priority system. Passive priority does have the benefit of being lower in cost, however it has limited potential to improve bus operations.

Table 1 - Summary of BSP Strategies

Control Strategies	
Real-time	Priority changes based on constantly updated information
Fixed-time	Applies a fixed plan to make decisions regarding priority
Schedule-based	Priority awarded based on the bus schedule
Headway-based	Priority awarded based on the headway between buses
Priority Concepts	
Active priority	Signal is adjusted for each bus on detection at intersection approach
Passive priority	Signals are adjusted to suit the bus schedule along the route

BSP SYSTEMS

Bus Information and Priority System (BIPS) offers bus priority without the large increase in delays to other traffic (5). BIPS is an active real-time system that can utilize different methods of detection. It considers the entire bus priority system as a network that contains interacting buses and intersections. BIPS utilizes five modules to exchange information and determine what kind of priority should be given to each bus. The modules used are:

- Projection on Route Module receives bus-positioning messages (wave based, dead reckoning and beacon systems may be utilized) and then returns information.
- Traffic Flow Estimator Module receives traffic volume information and then returns congestion information and estimates the degree of congestion and travel time.
- Travel Time Prediction Module receives information about the status of signals later on in the route of the bus and determines an estimated time for travel through the route.
- Priority Processing Module communicates with the travel time prediction modules to get information on various data.
- Monitor and Control Module starts the other modules and communicates between them.

Microprocessor Optimized Vehicle Actuation (MOVA) is a bus priority system that utilizes a signal control system to analyze lane data and control signal timing (6). MOVA is an active real-time system. The system has been tested on isolated junctions in England using transponders and loops in the road, although other methods of detection can be used with the system. MOVA employs a variety of bus priority techniques depending on the situation of each priority request. If the transit vehicle is arriving when the light is already green, the green signal can be extended to allow enough time for the transit vehicle to travel through the intersection under normal conditions. If the transit vehicle is arriving when its signal is in a red phase, the other phases can be skipped or truncated, depending on the situation.

Split Cycle Offset Optimization Technique (SCOOT), an active urban traffic control system, provides real-time optimization (4). Bus priority is given via green extension, green recall, and re-synchronization. Various detection methods can be used with the system such as transponders and AVL. The SCOOT software has the benefit of preventing early termination of bus priority phases, extend phases, or recall the phase. In order to perform such functions, SCOOT applies different “weights” to each decision. The decision is then made to “advance” (bring the phase forward four seconds), “stay” (not change), or “retard” (delay the phase for four seconds). Selective Priority Network Technique (SPRINT) is an active fixed-time system based on many priority principles from a system called “PROMPT” (PRiority and InfOrMatics in Public Transport) (10). The SPRINT system detects buses with loops in the road surface and transponders on the buses. The system decides new signal timings that allow a bus to travel through the next intersection using green extension and recall. Constraints are built in to reduce delay to non-transit traffic. Maximum extension limits are in place. After allowing one recall, the system cannot perform another recall until one cycle has passed with no recall. Compensation is also provided.

Signal Progression Optimization Technology (SPOT) uses a decentralized approach. SPOT, tested by Fox et al (7,8), is the intelligent signal control processor of Urban Traffic Optimization by Integrated Automation (UTOPIA). This is an active real-time BSP system. UTOPIA considers non-transit vehicles, along with transit vehicles, within a hierarchical decentralized traffic adaptive control system. The system optimizes the total travel time with constraints of average speed and saturation flows. Problems are classified into a lower level (at the intersection) or a decision level (over the entire area). It uses the Texas Instruments Radio Identification System (TIRIS) tags for automatic detection. These tags pass by loops in the road and give the location of the bus to the computer. It minimizes cost functions over a rolling horizon of two minutes and co-operates with the nearby intersections by exchanging traffic information. Phase change times are limited by phase order and duration limits. The field trial of the enhanced SPOT system performed in Leeds, England reduced travel time by approximately 10 percent. Non-transit vehicle travel times were unchanged.

The “Opticom” system by 3M uses infrared communications between buses and intersections with emitters on the bus and detectors at the intersection. In a stand-alone system the driver activates the emitter. A link can be established to switch off the emitters when the doors are open so that priority is not requested while the bus is stopped. Opticom bus priority control systems have been implemented at over 40,000 intersections worldwide and have been used to give priority to both emergency and transit vehicles. This is an active real-time system.

PROS/CONS OF PRIORITY METHODS

An Al-Sahili and Taylor study from 1996 (2) concluded that the maximum benefit a bus can gain under the tested conditions was an average of 75 seconds out of 22 minutes 41 seconds – or 6 percent. This serves as evidence of the varying degrees of effectiveness of BSP. The test conditions

in that study were 14 intersections in Ann Arbor, Michigan. The test used only green extension, red truncation with and without compensation, and skip phase with and without compensation. They concluded that the overall benefits gained by buses were not sufficient to counter the delay to other vehicles. They also determined the best bus priority is one which combines elements of various systems for each intersection. Other studies have produced greater benefits with BSP, illustrating the importance of choosing the correct system for a particular corridor. A Weesner and Meyerkord study concurred (26), suggesting any effective bus priority must be tailored to suit each area and no one plan can be implemented uniformly and be effective.

A study presented at the International Conference on Traffic and Transportation Studies in 1998 (18) tested the effectiveness of bus priority with a simple two-intersection arterial. Each link was 200 meters apart and the signals ran with a 60-second cycle length. The extension and truncation period was five seconds for either priority method. The study performed one test without any priority, then one with priority. The average reduction in journey time with priority was 10.3 percent, with maximum reductions ranging as high as 37 percent.

The study did make note of the fact that in some instances a bus may actually take longer to complete a journey with priority. This is due to congestion that may arise from previous priority and the bus missing a suitable time for priority to be granted. However overall, priority was proven to reduce bus journey times. Non-transit vehicle delay was not examined in this study.

Jacobson and Sheffi developed delay models for testing traffic impact with signal bus preemption in 1980. The results of their tests revealed that the greatest benefits to all traffic with bus signal priority could be obtained by adjusting signal cycle and phase duration.

By reviewing existing literature, the authors have gleaned that each system examined in this report has both pros and cons, some of which are outlined in the following table.

Table 2 - Pros and Cons

BIPS:

Pro	Con
<ul style="list-style-type: none"> ➤ Considers buses in both directions 	<ul style="list-style-type: none"> ➤ The use of an indirect priority strategy in heavily congested traffic that just tries to clear the way for oncoming priority vehicles may be less effective than other systems in areas with heavy congestion.

MOVA:

Pros	Con
<ul style="list-style-type: none"> ➤ Produces significant reduction in delay for buses ➤ Ability to award different types of priority ➤ Limit on the amount of priority that can be given to vehicles per hour 	<ul style="list-style-type: none"> ➤ Still inconclusive evidence of how it affects some non-transit traffic

Opticom:

Pros	Con
<ul style="list-style-type: none"> ➤ Saved transit buses an average of up to 15 seconds per intersection when implemented in Phoenix, Arizona ➤ Buses ran closer to schedule and ridership showed an increase in Charlotte, North Carolina ➤ Average bus run time was reduced by 23.8 percent and average travel speed increased by over 30 percent 	<ul style="list-style-type: none"> ➤ Opticom does result in some delay to non-transit traffic. With the OPTICOM system tests in Phoenix, Arizona, there was a small increase in delay of 1.4 percent to other traffic.

SCOOT:

Pro	Con
<ul style="list-style-type: none"> ➤ SCOOT can work on a short-term traffic issue, while also noticing trends over time. 	<ul style="list-style-type: none"> ➤ Bus times are not significantly changed for buses going against the peak flow of traffic during the PM hours in relatively un-congested traffic, because the car flow against the bus is given green coordination.

SPRINT:

Pro	Con
<ul style="list-style-type: none"> ➤ The SPRINT system in London produced an average of 2.0 seconds reduction in delay per junction for buses on the main road and 6.4 seconds reduction on side roads. 	<ul style="list-style-type: none"> ➤ The below average test results from London indicate that the system works best in less congested areas.

SPOT:

Pro	Con
<ul style="list-style-type: none"> ➤ The field trial of the enhanced SPOT system reduced travel time by approximately 10 percent. 	<ul style="list-style-type: none"> ➤ Delay at certain intersections to traffic driving in opposite direction to priority traffic.

PROJECTS IN NORTH AMERICA

Across North America, transit and highway agencies are working closer together than ever before to address transportation problems facing their communities. This increasingly cooperative environment is leading these agencies to embrace operational strategies that can increase the amount of people transported, not just vehicles. Although these strategies are being embraced, skepticism still remains regarding their effectiveness. Some of the case study projects across North America are featured in this report to give an overview of the type, benefits and costs associated with BSP projects.

Los Angeles

A Los Angeles regional transit authority survey showed that bus passengers cited the long duration of journeys as the biggest problem with the bus system (22). Bus speed had declined in the area by 17 percent in just a few years. In order to solve this problem, the transit authority initiated a project that adopted many bus priority strategies from a program in Curitiba, Brazil (20).

LADOT implemented a \$10 million signal priority project on two demonstration corridors (Ventura Boulevard and the Santa Monica-Beverly Hills-Montebello route) in the City of Los Angeles. The system was installed at 210 intersections and used 331 loop detectors with more than 150 transponders. Initial results from LADOT were 22-27 percent reductions in bus travel time. LADOT is in the process of evaluating the TSP project and have proposed expanding the TSP program to other major transit corridors if the initial results hold up in their final analysis.

The system grants early green, extension, free hold (hold a signal green until the bus passes through the intersection), and phase call (brings up the selected phase that is not normally activated, typically for queue jumper or left turn) priority modes. Buses are dispatched every 3-10 minutes and can be instructed to slow down or speed up (within the speed limit) to avoid bunching up with other buses.

In order to reduce delay to non-transit traffic, software was created that placed limits on any green extension to ten seconds. Even if the intersection is saturated with buses requesting priority, the system will grant only ten seconds. Additionally, at highly congested intersections, green extension is only implemented in every other cycle.

The Ventura Boulevard route decreased bus travel time by 25 percent and the Santa Monica-Beverly Hills-Montebello route also experienced a 25 percent reduction. It should be noted that in addition to priority techniques, the bus routes had their number of stops reduced from a two-tenth-mile minimum between stops to an eight-tenth-mile minimum. Additionally, low floor buses were used that are easier and quicker to board. Furthermore, in order to encourage passengers to exit from the rear of the bus, large signs were posted and the drivers verbally direct passengers in that direction. Despite these additional improvements, project officials credit (subjective) 30 to 40 percent of the 25 percent reduction to bus priority technology.

The LA system uses a Model 2070 traffic signal controller. This is a first generation Advanced Transportation Controller (ATC) designed by the LADOT and California Department of Transportation. LADOT staff developed all of the software.

Each intersection is equipped with sensors at the controller cabinet and inductive loops for each direction. Buses equipped with transponders are detected when traveling over loop detectors. The sensor unit in the controller transmits the bus ID number to the computer. No priority is granted if the bus is early or running on schedule. However, if the bus is late then the controller will provide priority in order for the bus to catch up with the schedule.

LADOT is currently testing a prototype system with AVL that would communicate the arrival time information of the next bus from the ATSAC (Automated Traffic Surveillance and Control Center) to changeable message signs at the bus stops.

Portland

Portland has conducted tests of bus priority with the 1993 Powell Boulevard test, and the 1994 Multnomah Boulevard test (11, 15). These tests revealed that systems that require bus operators to manually request priority to the traffic signal while operating the bus are not efficient methods. The bus driver often failed to call for priority. A test of Opticom (green extension/red truncation control)

was quite effective, although the software required enhancements. The Powell Boulevard test did reveal a benefit to bus priority, but the two-mile stretch of road used for the test was too small to reveal any statistically accurate figures for a citywide implementation. However, these studies did lead the way for a \$5 million project that included the installation of optical emitters on the entire standard bus fleet (775 buses), and a revision of the on-board AVL (Automatic Vehicle Location) system to activate the emitter. In addition, a “2070” generation controller and optical detectors were installed at intersections. This project provides complete signal priority for five major bus routes in Portland.

Tri-Met, Portland’s public transportation provider, wanted to improve transit performance and reduce delay to buses in order to provide a more viable alternative to driving a car. Additionally, Portland created a BSP system with the objective of reducing operating expenses to allow either enhanced headways, or additional services elsewhere. They also wanted to implement BSP without increasing delay to non-transit vehicles. Furthermore, in choosing their system, they implemented Opticom from 3M due to the ability to also use the system for emergency vehicles. It was important for Tri-Met to improve transit and also improve emergency signal priority and not interrupt any preemption for emergency vehicles.

The technology behind the Portland system is the Bus Dispatch System (Tri-Met’s AVL system). An on-board GPS (Global Positioning System) satellite receiver determines the location of the bus. If the bus is running late (classified as over 7 minutes) then the Opticom emitter is activated to initiate priority. The bus then receives priority through intersections. However all emergency vehicles have a “high” priority setting that overrides the transit’s “low” priority setting.

To date this project has been implemented at sixty intersections. The current system only initiates priority when a bus is running behind schedule. To use priority at other times to speed up transit would have required changing their schedules to account for buses running quicker. The decision was made to wait until new schedules are created to make changes. Tri-Met is in the middle of evaluating the system and have yet to release any documented information about the benefits of the system.

Seattle

The King County Department of Transportation in Seattle implemented signal priority in the 2.1 mile Rainier Avenue System (activated in the spring of 2000), which includes nine intersections, five with priority. A report from King County (3), reported that they had many objectives with their BSP system. They wanted to improve their ability to transport people and improve transit performance. In theory, an improvement in transit performance provides additional incentive for people to switch modes. Additionally, the system was designed with non-transit vehicles in mind, to avoid any delay to those vehicles. Another primary objective was to avoid implementing a

limited control system that disrupts the flow of traffic. Subsequently, a system with a large amount of functional priority control strategies was deemed necessary.

King County is the most recent major agency to initiate a major transit priority project and produce a final report on their initial experiences. Therefore, data from their study is included in more detail than most other case study areas. The following information is summarized from the Rainier Avenue System Project Final Report (27).

The hardware for the system included the Amtech RF (radio frequency) tags on the buses, Amtech log periodic antennas on the road, and the Transit Priority Request Generator. To run the system, The City of Seattle used a combination of controllers. The system is made up of Eagle, PEEK LMD 9600 and Econolite controllers. The combination provided the depth of function required to avoid any problems they experienced with a “preempt only” type system. They worked with the controllers to change timings and developed the following firmware implementation requirements:

- Traffic signals shall extend their green interval for approaching priority vehicles
- Traffic signals shall shorten red displays for approaching priority vehicles
- Traffic signals shall not shorten any minimum or clearance intervals
- Traffic signals shall not skip any phases
- Traffic signals shall not break coordination if a BSP service call is requested.

The A.M.-peak period along Rainier Avenue experienced a 2.3-second/vehicle (13 percent) reduction in average intersection delay. Their study also considered delay to the minor street movements. Minor movements include all side street movements and the protected main street left turns. The A.M.-peak period featured a reduction in minor movement delay of 0.9 seconds/vehicle (3 percent). Midday-peak period delay increased slightly, although the level of service remained the same.

Before and after studies conducted by King County Metro show that TSP reduces the average intersection bus delay by approximately 5 seconds per TSP-equipped intersection – a reduction of 24 percent to 34 percent for TSP-eligible buses. In addition, intersection bus delay is reduced by an average of 34 percent when a bus is eligible for priority treatment.

One critical result of the study is there were no side street cycle failures. This means the reduction in green time for side streets caused by TSP did not cause any side street vehicles to wait through more than one green signal cycle. King County concluded that transit priority produces minimal side street delay that is likely unnoticeable to the driver.

The experiences gained from the field study brought King County to recommend “tailoring the specific control and transit operating strategies to the time periods where TSP is being deployed

seems to have the greatest potential for benefit in terms of reduction in person delay.” They also state, “TSP implemented in a moderate way (i.e., no phase skipping, minimal impact on coordination, etc.) is virtually unnoticeable by the motorist.”

The first of 26 intersections of the Regional Transit Signal Priority System has been successfully deployed at the intersection of Genesee Street and Rainier Avenue. The initial results show:

- A 50 percent reduction of signal related stops by prioritized buses
- A 57 percent reduction in average delay for the prioritized buses
- A 13.5 percent decrease in intersection average person delay
- Average intersection vehicle delay did not change
- A 35 percent reduction in bus travel time variability for the prioritized buses
- Effects to side street delay were insignificant and there was no significant change to non-priority approach queue lengths

King County Department of Transportation reports that the reduction in delay at signalized intersections resulted in transit patrons experiencing a smoother and more comfortable ride. Additionally, the reduction in stops reduced the transit operator’s workload.

Orlando

The Central Florida Regional Transportation Authority, commonly known as Lynx, started providing service on an improved downtown circulator, Lymmo, in August 1997. Even though this is a bus rapid transit (BRT) project, it is featured here because two of the intersections have special phases for Lymmo buses. The service offers exclusive lanes for the entire 2.3-mile route, in addition to signal pre-emption, AVL, and free fare, so there is no fare collection delay.

The total capital cost for Lymmo was \$21 million. There is no documentation of costs for implementation and operation of the BSP system for the two intersections. Orlando did not use an outsider supplier for hardware; they designed the system themselves. Because Lymmo operates in contra flow lanes, all bus movements at intersections are controlled by special bus signals. To prevent confusion, these signal heads use “white” lines instead of the standard red, yellow, and green lights. When a bus approaches an intersection, a loop detector in the bus lane triggers the intersection to allow the bus to proceed either in its own signal phase (e.g. when making turns not otherwise permitted) or at the same time as other traffic is released when no conflicting traffic movements are permitted.

One of the direct benefits of having BSP at two intersections is Lymmo is able to keep on schedule. Waiting time is lower for Lymmo compared to its predecessor Freebee, if dispatchers were to use

the AVL system to instruct drivers to hold early buses to adjust to the schedule in order to achieve a more even distribution of headways.

Miami

The South Dade Busway is a two-lane bus-only roadway constructed in a former rail right-of-way adjacent to US 1, a major arterial. The Miami-Dade Transit Authority (MDTA) opened this busway in February 1997. BSP for busway buses is available at six signalized intersections along the whole corridor. The system uses type 170 controllers by Safetran signal control. The BSP timings and software were designed by the MDTA and internal agencies rather than using an outside vendor.

In the northern portion of the busway, there is very little separation between US 1 and the busway. At these locations, the traffic signalization was designed so that the busway intersection and US 1 intersection would function as one signal system. The signal facing busway traffic is red unless a loop detector senses an approaching bus. If a bus is detected and if US 1 has a green signal, the busway also gets a green. If US 41 has a red signal then the busway and US 1 get a green signal and the left and right turns get a red signal.

In the initial months of operation there were 14 collisions between buses and sidestreet traffic. In every case, the private vehicle driver had not noticed or had ignored the red signal at the busway. The signalization was changed in August 1997 so that the busway signalization was synchronized with US 1. From August 1997 to July 1998 there were five collisions, a much lower rate than in the first months of operation. Right turns from side streets to US 1 were facilitated by installing a right turn lane and right turn signals. Also, the drivers of the transit vehicles have been instructed to be more alert and slow down at these intersections. Right turns (south to west) from US 1 to side streets are permitted only on green arrow, to prevent right-turning vehicles from colliding with busway traffic.

The busway cost \$60 million: \$17 million for right-of-way acquisition and \$43 million for construction (including eight miles of two-lane roadway and 15 stations). There is no documentation of costs for implementation and operations of the six BSP intersections. The South Dade busway seems to have provided little (less than 10 percent) or no timesavings for transit vehicles. However, ridership in the corridor increased 49 percent on weekdays, 69 percent on Sundays, and 130 percent on Saturdays, as of May 1998. This increase in ridership indirectly can be attributed to BSP. However, increased ridership has resulted in longer and more frequent bus stopping.

WHEN IS NON-TRANSIT TRAFFIC LEAST AFFECTED?

The effect of priority on non-transit vehicles tends to vary depending on the level of congestion. In general, compensation to non-transit traffic is easier in areas with low congestion. Documented test results of most BSP systems have shown that some small delay to non-transit traffic is inevitable. The field trial of the enhanced SPOT system performed in Leeds reduced travel time by approximately 10 percent. Car travel times were unchanged. However, most systems are tested or implemented on just two or three intersection corridors, meaning that test results may be misleading for practical applications. No one system has the perfect priority strategy for non-transit vehicles. Some elements of a priority system to ensure traffic operations are least affected are discussed below. The box provides a summary of this section, with a more detailed discussion below.

- Real-time control strategy is preferable
- Delay can be minimized with constraints on maximum and minimum greens
- Software with a weighting system has potential to reduce delay to non-transit vehicles
- Initiate priority only when bus is running late
- Indirect priority strategy

Real-time control strategy is preferable and has far more potential to reduce delays to non-transit traffic. If the system uses a program such as TRANSYT to calculate signal timing plans and then selects which plan best suits the current traffic conditions, operators can adjust the signal timings in the event of increased congestion, accidents, or other unforeseen events.

Although real-time control is preferable, it is not without flaws, such as:

- Some systems cannot consider two or more transit vehicles approaching an intersection from different approaches.
- Real-time signal systems require high-speed computers and communication systems that raise the cost of implementing the system. In addition, computation times for each control decision can often take too long. However with progressing technology, both these issues are becoming less and less of a problem.
- The signal timing prediction models some systems use may not be reliable in practical applications because of variations in traffic volume, unforeseen events, and the impact of priority itself.

At the intersection level, delay to non-transit vehicles can be minimized with constraints on maximum and minimum greens. In order to reduce delay to non-transit traffic, software should be created to place limits on any green extension to a maximum amount (e.g., 10 seconds). Even if the intersection is saturated with buses requesting priority, the system should only grant this

maximum amount of time. Additionally, at highly congested intersections, green extensions should be limited to every other cycle. Compensation should also be provided.

Software with a weighting system at intersections may be used to reduce delay to non-transit vehicles. Different weights can be created with the highest weight meaning the system grants priority immediately, while the lowest weight indicates no priority should be awarded. The weights in between would give green extension only and give green extension/recall with a level of constraint determined by the congestion of non-transit traffic. The ratio between bus headway and expected headway constitutes the degree to which the bus is said to be running behind schedule. The weight would depend on how late the bus is running.

Another simple solution to reduce congestion to non-transit traffic is to initiate priority only when the bus is running behind schedule.

In heavy congestion, an indirect priority strategy might work – this tries to clear traffic ahead of a bus. Since bus arrival time is often difficult to accurately determine without a fully operational AVL system, this type of system may just attempt to clear as much congestions as possible along the bus route.

CHARACTERISTICS OF AN IDEAL BSP SYSTEM

Systems operate with a variety of different techniques that aim to reduce delay to transit vehicles. The methods of priority used are all relatively effective, with each system using a mixture of different priority techniques. Some of the ideal elements of a priority system are as follows:

- Ability to track bus movements accurately. Most systems developed now apply some form of automated vehicle location. A system that constantly tracks the location of a bus is ideal. Rather than relying on the bus to cross a sensor in the road, a more advanced system would know if a bus has been delayed before reaching the next intersection. Any system that operates as a network of intersections is less effective without constant monitoring of bus location. This also could be integrated into real-time passenger information services to provide estimated arrival times.
- Ability to measure and record statistics on the bus routes to form transit plans based on statistical analysis. Also consider traffic volume, passenger occupancy and other related figures.
- Ability to offer a wide variety of priority techniques for different situations.
- Ability to minimize delay to non-transit traffic and offer compensation.

- Ability to estimate cost to both passenger and transit agency (based on average delay) associated with enacting any given priority method.

PROFESSIONAL OPINIONS ON BSP

Five transit planners and five traffic engineers were interviewed for this report. All professionals interviewed worked for transit agencies in the United States that have implemented BSP systems. They agreed to the interviews on the basis of remaining anonymous within the report. The table provides a summary of their comments, with more detailed comments below.

Table 3 – Professional Opinions

Issue	Transit Planners	Traffic Engineers
Effectiveness of BSP	Reduces delay to buses.	Promotes transit as alternative mode.
Delay to Non-Transit Traffic	No noticeable delay to side traffic.	Delay considered in design.
Where to Put BSP	Placed on corridors with highest ridership.	Picked routes with most delay.
How to Implement BSP	Relocated bus stops.	Revised controller firmware and timing strategies.
BSP Technology	Success of vendor's systems is dependent on implementation.	No BSP vendors are truly proven.
Public Perception of BSP	Little public reaction.	No feedback received.

Effectiveness of BSP

All transit planners involved in Bus Signal Priority (BSP) think BSP improves a transit agencies ability to move customers:

- One transit planner who has implemented BSP says that, "it clearly reduces delay to buses." All of the traffic engineers concurred that it does improve the ability to move people.

The transit planners all believe that BSP meets needs that are not being met by current congestion mitigation methods. One transit planner stated that BSP provides a faster, more competitive trip by bus. This allows buses to provide a more viable alternative for customers than merely driving:

- “When installed on a corridor basis, Transit Signal Priority could reduce operating expenses for the current frequency, allowing either enhanced headways on that line, or additional or new service elsewhere.”

Another transit planner concurred, stating that BSP can increase the number of people who use buses if the movement and seat capacity of buses is also improved. A traffic engineer said that BSP is just one way to promote transit as an alternative mode. Another engineer pointed out:

- “It will take a number of years to install BSP at all intersections. There are also a number of intersections where there are congestion problems that do not have transit routes. It meets some very specific location problems, but not all.”

Delay to Non-Transit Traffic

Although some lacked sufficient data to substantiate findings, no agency experienced any significant delay:

- Transit planners interviewed for this study explained that BSP did not create any significant delays to non-transit vehicles.

One transit planner did report a measured increase in delay to side street traffic of 4 seconds per vehicle. However such a delay was not noticeable to those non-transit vehicles and the person delay rate actually decreased because of BSP.

Another transit planner said that they conducted a detailed study to quantify any traffic operation concerns such as delay to non-transit vehicles. They looked at intersection delay, side street delay, cycle failures, and complaints. They kept that information in mind when designing the system.

Regarding delay, a transit planner said that in modeling, no net loss was clear:

- Although a few locations did experience small delays, a few experienced small improvements.

Furthermore, “in preliminary testing, no significant impacts or delays were perceived.” That agency is treating non-transit delay as a significant issue. In 2001, as transit signal priority is implemented on their entire corridor, they will test the impact. In addition, a different transit planner stated that, “care is being taken at every intersection that adjustments will not drastically impact other traffic movements.”

A traffic engineer said that although they have no data for delay to non-transit vehicles because their system is not operating yet, they do have political support from the city. Another traffic engineer explained that they did consider the potential delay when designing the system. Subsequently their system just gives extended time in phases, because they were not willing to skip phases entirely.

Where to Implement BSP

In all cases, a high degree of planning and testing went into determining which corridors would receive BSP:

- In order to determine suitable coverage for BSP, one transit planner developed an Excel spreadsheet to estimate expected bus performance improvements. That tool estimates productivity by analyzing the number of buses and passengers, bus arrival patterns, signal phasing, and relative green/red split time.

Many transit planners installed BSP on the corridors with the highest ridership and frequency. A transit planner explained:

- “This means that the technology benefits the largest number of passengers and provides the greatest chance for enhancing the efficiency of resources used.”

In order to ensure the system would be effective, “extensive testing occurred on the technology itself. In addition, short test corridors were implemented and time savings measured.” That transit planner also said an analysis of the before and after statistics would be conducted to determine the effectiveness of BSP.

- A traffic engineer explained that they chose “those routes with substantial delay” for their BSP systems. Another engineer stated that they used NETSIM to evaluate the simulated effects before opening the system.

How to Implement BSP

Transit planners did make some changes to operating characteristics in order to implement BSP. One planner explained that they worked with transit scheduling to take some time out of the schedule. Other steps taken were:

- Relocating bus stops to provide far-side stops where possible, and retiming and optimizing the signals.

The traffic engineers of that city “worked with traffic controller vendors to revise controller firmware to provide enhanced signal logic.” The traffic engineers also had to develop BSP timing strategies that were appropriate for their corridors.

On the issue of the far-side stops, another transit planner agreed, noting that most of their bus stops had previously been near-side of intersections. He commented:

- “Since BSP operates more effectively on farside stops, part of the process has been to try to move stops to the farside of signalized intersections.”

One traffic engineer did state they made no changes to existing operating measures in order to implement BSP. Another engineer stated that some changes were made to “fine tune” traffic control.

BSP Technology

Most of the transit professionals believe the field of BSP vendors is unproven. One transit planner used a detection system based on RF technology that was “chosen and designed based on a regional oversight committee of local traffic engineers.” That transit planner stated that, “the detection system in of itself does not provide priority since that is the traffic controller’s function.” He went on to state:

- “As an example I would not consider 3M Opticom (or other detection system vendors) a BSP vendor since the success of an Opticom system is completely dependent on how the priority control strategies are implemented.”

An engineer agreed, pointing out that no BSP vendors are truly proven. It was agreed by many engineers that:

- It is critical for the traffic engineers to develop the priority control strategies.

Nevertheless, one transit planner did choose the Opticom system, largely because:

- “The benefits (of Opticom) can be doubled by using the system for emergency vehicles at a higher priority as well.”

The planners did experience some difficulties when they tested the LoopComm embedded loop system (transducer technology used to “tag” vehicles for detection) and TOTE radio systems (the radio frequency part of the detection tag).

Public Perception of BSP

There was not an overwhelming public response to BSP, although some impact was felt:

- One transit planner did report some interest from the public about BSP. He stated there have been several press releases.

One other planner commented that, “not enough of the system is on-line for anyone to notice yet.” However it was noted that:

- “In public meetings and mailings, we have described the system, focusing on the benefits of reducing transit travel time, increasing the number of intersections with emergency signal priority, and making it very clear that bus priority will not interrupt emergency vehicle preemption.”

An engineer stated that although the public likely notices the different signals they have for buses, no feedback has been received.

SIGNIFICANT ISSUES OF BSP

The following information is summarized from an extensive literature search. This section addresses the more prominent issues regarding the implementation and impact of BSP.

Impact of BSP Strategies

- Unconditional signal priority should be reserved for express bus service during off-peak hours (9).
- Unconditional signal priority should be regulated by placing limits on green extension and red truncation lengths, especially at intersections with busy cross streets (9).
- Active signal priority may cause disruptions along highly saturated cross streets that do not dissipate before the next priority call (9).
- A real-time signal control model is generally considered more flexible in accommodating bus operations than a fixed-time control model. The performance measures for a bus-actuated system are better than for a fixed-time system when also considering the side street traffic (17). However, due to the difficulties of processing on-line data concurrently, both control models fail to treat on-line transit operations effectively (17).

- Though almost all systems provide reasonable control features, some still fail to treat two or more transit vehicles coming concurrently from different approaches (17).

Network-Wide Impacts of BSP

- It was noted that when preemption took place at a highly congested intersection (at saturation) preemption effects continued for several cycles (2).
- The presence of a single heavy-volume intersection in the network can skew the overall network statistics. The weights of these intersection MOEs (Measures Of Effectiveness) were very significant in the overall network MOEs (2).
- If significant changes are introduced to travel times for general traffic, route choice effects may result in increases in vehicular travel for vehicles using the main arterial, or for those experiencing increased delays at minor approaches to intersections where buses are given priority (13).
- Temporal effects may accompany such spatial impacts, such as changed peak period trip starting times, to avoid increased congestion (13).
- The advantage of considering bus priority in a network is to achieve a stable and optimal control over the relevant intersections provided that the predicted bus arrival times at these intersections are reasonably accurate (5).

Impact of Congestion

- The direct priority strategy is suitable for traffic situations with a low degree of congestion (5).
- The indirect priority strategy is suitable for traffic situations with a high degree of congestion (5).

Bus Travel Times

- The holding control parameter (determining how long traffic is held) is the most critical decision-making variable in bus controls at bus stops. Holding control can significantly improve the regularity of bus movement. With holding control, the average wait time of passengers decreases. However, the average in-vehicle time of passengers and the average bus travel time increases. Under schedule-based control strategies, early buses should be

held until the pre-planned schedule. Under headway-based control strategies, early buses should not be held until the pre-planned headway (17).

- Schedule-based controls are easy to implement because they do not need information of bus locations. In addition, schedule-based controls improve the on-time performance of bus service. This is very important for long headway situations (17).

Placement of Bus Stops

- Changes in the positioning of bus-stops could alleviate some problems associated with BSP (6).
- If the bus-stop is placed after the junction, the bus detector could be positioned further upstream on the approach giving more advanced notice of the approach of buses. If a bus lane could also be added, buses would be less impeded from reaching the junction (obviously) and the benefits would be even greater (6).
- Far-side bus stops should be used with active signal priority to ensure that signal priority calls are not wasted as transit vehicles dwell at bus stops (9).

IMPLEMENTING BSP

In order to assist a transportation agency to determine if BSP is appropriate and practical for their area, a series of checklists and spreadsheets were developed. In addition to determining appropriateness of BSP, these tools assist an agency in determining what changes may be needed for priority to function; and which methods of priority are best suited for their area.

The pre-implementation checklist was developed to determine if BSP is viable in a given area. The guidelines were created to determine any necessary changes for priority and which methods of priority are advisable.

The pre-implementation checklist is a tool to conduct a benefits assessment of BSP and identify which priorities to implement. The BSP assessment tool is extracted from the SCRITS (SCReening for ITS), a spreadsheet analysis tool developed by the Federal Highway Administration (28) (<http://www.fhwa.dot.gov/steam/scrits.htm>) for estimating the user benefits of Intelligent Transportation Systems (ITS). The tool allows practitioners to obtain an initial indication of the possible benefits of various ITS applications. The revised SCRITS spreadsheet will be posted on the FHWA website.

The BSP operational and design guidelines are for use by practitioners once the decision is made to invest in BSP. These guidelines help to identify what type of priority should be implemented based on certain preferences.

Bus Signal Priority Analysis (BSP) Benefit Assessment Tool

Appendix A contains the Analysis of Bus Signal Priority spreadsheet, which is one of 16 different applications included in the SCRITS spreadsheet. The spreadsheet contains sections on pre-implementation, bus and traffic operations, costs and benefits as well as an intersection specific guideline. Overall, the BSP spreadsheet allows the user to calculate a benefit/cost ratio to determine the effectiveness of BSP.

Much of the analysis requires information one may not have access to unless BSP had been implemented or seriously evaluated. In addition, the original spreadsheet calculated benefit/cost ratios based on BSP performance in other areas. Thus, the resulting ratio may not be accurate if some variables are in place that would adversely affect BSP performance. The changes made to the spreadsheet makes it possible for the user to determine if proceeding with BSP and determining the variables for the benefit/cost ratio is a practical option for a particular application area.

Pre-Implementation Checklist

The pre-implementation checklist contains a series of questions to assist agencies with determining the suitability of BSP. In most cases changes can be made to increase the viability of priority. The checklist is essential in determining critical factors that may impede BSP's benefits.

The first two questions address express bus service issues with BSP. For instance, off-peak express service allows for unconditional priority – saving time for transit but may cause delays in other service areas. Far-side bus stops also have an effect on BSP. For instance, the existence of far-side stops (or at least a willingness to relocate stops to far-side) increases the potential benefits of BSP.

Although most BSP systems attempt to minimize delays to non-transit traffic, in cases with highly saturated cross streets (1.0 v/c ratio), priority can cause complications. The v/c ratio measures the flow of traffic in relationship to a theoretical determination of the capacity. Subsequently, an agency with a large number of highly saturated cross-streets may want to re-consider priority, at least at those intersections. Although the existence of saturated cross-streets does not preclude BSP, some concessions must be made. Hence the additional recommendations at the end of the checklist suggest that the active priority method has limited potential with the highly saturated cross streets.

Related to the saturated cross-streets are heavy volume intersections in the network. A network that contains several highly congested intersections may limit the potential of BSP. Although improvements may be noted, there may not be enough benefits to justify implementation of BSP. If the other variables are in place to make priority a viable option, the “intersection specific guidelines” section (explained in further detail in subsequent section) can be used to gauge the impact of congestion.

Many BSP systems implement techniques to address two transit vehicles simultaneously requesting priority at the same intersection. However, if this scenario is likely to occur frequently, BSP has limited potential. Many agencies award priority to the route with the most passengers, an effective technique if simultaneous requests occur relatively infrequently. However, if this scenario is likely to occur on a regular basis, a negative impact will arise on the direction not receiving priority. Therefore this is a significant variable to consider.

Finally, if AVL technology is already installed, BSP becomes much easier to implement and more beneficial.

Based on the users inputs to the series of questions, the spreadsheet recommends the potential implementation of BSP:

- If there are only one or two answers that make priority beneficial, then the output of "changes needed for priority" appears.
- If there are three beneficial answers then priority is somewhat recommended.
- Four advantageous answers output a recommendation to pursue priority.
- Five or six positive answers results in priority being strongly recommended.

No recommendation is made to not pursue priority as, by analyzing the answers, a few changes (such as relocating bus stops) may turn priority into a beneficial proposition.

Table 4 - Pre-Implementation Checklist Point System

Pre-Implementation Checklist	If Answer is Yes	If Answer is No
Express bus service?	Plus One Point	No Point
Express bus service during off peak?	Plus One Point	No Point
Farside bus stops?	Plus One Point	No Point
Highly saturated cross streets over 1.0 v/s ratio?	No Point	Plus One Point
Heavy volume intersections in the network?	No Point	Plus One Point
Many instances of two transit vehicles approaching one intersection?	No Point	Plus One Point
Do you have AVL technology installed?	Plus One Point	No Point

Intersection Specific Guidelines

This section recommends a priority strategy based upon the saturation level for a specific intersection (14). For example, if the saturation level is at 1.0 (v/c ratio) then priority may not be very effective. If the saturation level is under 1.0 and above 0.8, then 10-second priority is the best option. 10-second priority works best in this situation because any longer priority would result in too much delay. With a saturation level over 0.25 and less than 0.8, priority with some limits can be instituted. Due to the lessened saturation, more priority can be implemented without causing any delay. Unlimited priority can be considered with a saturation level under 0.25 because there is less possibility of delay.

Table 5 – Recommendations Based on Saturation Level

Saturation Level	Strategy
Under 0.25	Unlimited Priority
Over 0.25/Under 0.8	Priority With Limits
Above 0.8	10-second Priority
1.0	Priority May Not Be Effective

Operational and Design Guidelines

If an agency decides to investigate or implement BSP, the operational and design guidelines provide another tool to help identify the type of priority that should be implemented based on

certain preferences. Although one priority system may far outperform others in some areas, if the variables that make that system effective are not in place, the system may under perform. In addition, these guidelines consider various priority techniques and methods, and offer suggestions regarding technology or situation needs necessary for that technique to be effective and how it impacts the other technologies or methods needed.

Table 6 - Operational and Design Guidelines

1. Are you willing to change operating characteristics for BSP?

If YES then implementing an active, real-time system is advisable.	If NO then a schedule based, fixed-time strategy is best. Although this does reduce the benefits of BSP, it requires less adaptation of the current system.
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2. Are you willing to relocate stops to the far-side if not currently there?

If YES then the active priority system will have the most benefits	If NO then that limits the benefits possible with an active priority system.
---	---

3. Do you want an active priority system?

If YES then a real-time system with AVL is optimal. Should be noted that active priority has in some cases been less effective in areas with highly saturated cross streets.	If NO then a passive priority system is needed. Note that this limits potential benefits.
---	--

4. Do you want unconditional priority?

If YES then note that this is best suited to areas with low degree of cross street congestion. Unconditional priority is best suited to specific situations such as express bus service during off-peak. Unconditional priority with no limits can cause delays.	If NO then you need conditional priority. It is suggested to use a weighting system
---	--

5. Do you want to provide compensation?

Selecting YES means you have a concern that BSP could delay non-transit.	Selecting NO means that non-transit delay is not as significant an issue, perhaps due to low congestion levels.
---	--

6. Do you want to provide green recall?

Selecting YES is advisable if you are operating a passive priority system.	Selecting NO is advisable if you are operating an active real-time system.
---	---

7. Do you want to provide synchronization?

Selecting YES suggests you can program signal timings along an arterial to provide minimal stops.	Selecting NO means that a long section of synchronization is not practical along these arterials.
--	--

8. Do you want to offer phase suppression?

Selecting YES means cross-street saturation is at low levels.	Selecting NO means cross-street saturation is too high.
--	--

9. Do you want to offer real time priority?

If YES then AVL and active priority is advisable.	If NO then a fixed-time or schedule-based system is recommended.
--	---

10. Do you want to use a headway-based system?

Selecting YES is advisable to avoid buses bunching up.	Selecting NO is advisable if ridership and frequency of buses is high enough to justify one bus on the same route following relatively closely to another.
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11. Do you wish to apply different "weights" to certain situations?

Selecting YES suggests you are using a real-time, active priority system and have high levels of congestion.	Selecting NO means you are using a fixed-time schedule and do not have real-time priority.
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12. If using real-time, do you want a loop detector/transponder based system or an AVL based system?

Selecting an AVL system makes online information to transit users and implementing variables to when priority is offered far more practical.
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13. Do you want to offer priority only when running behind schedule?

Selecting YES limits benefits of reducing travel time.	Selecting NO means that schedules do not need to be updated and changed based on improved travel times.
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CONCLUSIONS

The key to an effective bus priority system is to ensure transit vehicles in all directions can be assisted without delaying non-transit vehicles to any extremes in the process. The degree to which priority can be afforded is limited by the potential delay to other transit vehicles and non-transit

vehicles that are delayed as a result of any granted priority. Most systems are able to provide ample priority to one direction. ***There is a lack of documented test results regarding the affect of BSP on non-transit vehicles, especially for projects that are in operation in North America.***

The interviews with planners and engineers involved in installing BSP projects revealed that BSP, although it has existed as a concept for about three decades, is still in relative infancy in terms of widespread implementation and study in the United States. ***Performance monitoring and benefits assessment studies for BSP are scarce. The perception of traffic engineers is that, provided the timing strategy if tailored for the area, non-transit vehicle delay is not significant.***

BSP offers fewer benefits in areas with extremely high bus volumes or very light traffic. Some test results concluded that the overall benefits gained by buses were not sufficient to counter the delay to other vehicles. The most appropriate priority method may be one that combines the various elements of existing priority techniques.

Overall, sufficient measures must be taken to prevent traffic operations being negatively affected by bus priority. ***Real-time control strategy is the best solution***, although any system must be designed with the particular area needs in mind. As the traffic engineers interviewed agreed, the engineers must develop control strategies that are appropriate for the given intersections in their area. The literature search did reveal ***the importance of implementing a direct priority strategy in areas with low congestion, an indirect priority strategy for areas with a high degree of congestion, and the use of a real-time system with a variety of priority strategies to minimize non-transit delay.*** However, although those valuable generalizations can be made about heavy or light congestion that can reduce delay, ***a specific approach for each area is the best solution to increasing the positive impact BSP can have on traffic operations.***

A “Pre-Implementation Checklist” to help determine the viability of bus priority in an area was developed. The checklist operates under the assumption of each variable being equally significant for bus priority. There was insufficient evidence to warrant considering one variable more significant than another. Further research may reveal some variables to carry a greater weight than others. The checklist is combined with the “Intersection Specific Guidelines” and Analysis of Bus Priority Systems spreadsheet in SCRITS. ***This checklist helps an agency determine how effective bus priority would be in their area and if any changes are needed prior to implementation. Once an agency has decided to move forward with BSP, the “Operational and Design Guidelines” determine which type of priority best suits the conditions of the area, or what design and operational conditions need to be changed to ensure the situation is suitable for BSP.***

REFERENCES

1. Abdelfattah, A.M. "Bus Delays in Mixed Traffic: A Challenge for Intelligent Transportation Systems." 69th Annual Meeting of The Institute of Transportation Engineers (ITE). August 1999.
2. Al-Sahili, K., Taylor, W.C. "Evaluation of Bus Priority Signal (BPS) Strategies in Ann Arbor, Michigan." Transportation Research Record 1554. Transportation Research Board, 75th Annual Meeting, Jan 7-11, 1996, Washington, D.C. pp. 74-80.
3. Atherley, Ronald. Rainier Avenue S. TSP Field Evaluation. King County Department of Transportation, 2000.
4. Bowen, G.T. "Bus Priority in SCOOT." TRL Report 255, Transport Research. Laboratory, UK. 1997.
5. Chen, W., Jargees, G., Drane, C-R. "New Approach for Bus Priority at Signalized Intersections." Transport Proceedings – Conference of the Australian Road Research Board 1998. ARRB Transport Research Ltd, Vermont, Australia. pp. 391-99.
6. Crabtree, M.R. and Vincent, R.A. "Bus Priority in MOVA." IEE Conference Publication 454. 9th International Conference on Road Transport Information and Control, 21st - 23rd April 1998. London. pp 85-89.
7. Fox, K., Haibo C., Montgomery, F., Smith M., Jones S. "Selected Vehicle Priority in the UTMC Environment." Institute for Transport Studies, University of Leeds. 1998.
8. Fox, K., Montgomery, F.O., Shepherd, S.P., Smith, C., Jones, S. and Biora, F. "DRIVE II project PRIMAVERA 2: Bus priority in SCOOT and SPOT using TIRIS." Traffic Engineering Control 36. June 1995.
9. Garrow, M. and Machemehl, R. "Development and Evaluation of Transit Priority Strategies." Public Journal of Transportation Vol. 2, No. 2.
10. Hounsell, N., McLeod, F. "Automatic Vehicle Location and Bus Priority: The London System." World Transport Research: Proceedings of 8th World Conference on Transport Research Meersman, H., Voorde, E.V.d.V., Winkelmann, W. Amsterdam: Pergamon. 1999. pp.279-92.
11. Hunter-Zaworski, K.M., Kloos, W.C. and Danaher, A.R. "Bus Priority at Traffic Signals in Portland: The Powell Boulevard Pilot Project." Transportation Research Record 1503. 1995. pp. 29-38.

12. Jacobson, J. and Sheffi, Y. "Analytical Model of Traffic Delays under Bus Signal Preemption: Theory and Application." Transportation Research B, Vol. 15B, 1981.
13. Jepson, D., Ferreira, L. "Assessing Travel Time Impacts of Measures to Enhance Bus Operations." Road and Transport Research, Vol. 8, No. 4. 1999. pp. 41-54.
14. Journal of Public Transportation Vol. 2, No. 2 99.
15. Kloos, W.C., Turner, K.R. "Implementing Traffic Signal Priority for Buses in Portland." Transportation Frontiers for the Next Millennium: 69th Annual Meeting of the Institute of Transportation Engineers. Las Vegas, Nevada. Aug 1-4, 1999. pp. 5.
16. Larson, R. M. Vehicle Detection – Phase III: Passive Bus Detector/Intersection Priority System. Washington, D.C.: Federal Highway Administration. Classifier Handbook, Oct 1977.
17. Lin, G.S., Liang, P., Schonfeld, P., Larson, R. "Adaptive Control of Transit Operations." November 15, 1995.
18. Liu, R., Clark, S., Montgomery, F., Watling, D. "Traffic Management Measures for Guided Bus Operation." Proceedings of the Conference on Traffic and Transportation Studies. Northern Jiaotong University, Beijing, China. July 27-29, 1998. pp. 181-91.
19. Miller, C., Deuser, R., Wattleworth, J., Wallace, C. Safety Evaluation of Priority Techniques for High-Occupancy Vehicles. Washington, D.C.: Federal Highway Administration. Final Report, Oct 1976 - Dec 1978.
20. O'Meara, M. "How Mid-Sized Cities Can Avoid Strangulation." World Watch Magazine. Sept/Oct 1998, Vol. 11, No. 5. Washington, D.C.: Worldwatch Institute. WWW: <http://usinfo.state.gov/products/pubs/livcomm/two.htm>.
21. Rothenberg, M. J. Priority Treatment for High Occupancy Vehicles: Project Status Report. Washington, D.C.: Federal Highway Administration. Interim Report, May 1976 - March 1977.
22. Sunkari, S.R, Beasley, P.S., Urbanik II, T., Fambro, D.B. "Model to Evaluate the Impacts of Bus Priority on Signalized Intersections." Transportation Research Record 1494. 1995. pp. 117-
23. Taub, A. "Rolling On: System Lets Traffic Lights Wave Buses Through." NY Times. Sept 9, 2000.

24. Thompson, A and Nicholls, J. "Signal Pre-Emption Using Traffic Control Networks." Traffic Technology International. 1997.

25. Urban Traffic Control and Bus Priority System Operations and Maintenance – Final Report. Washington, D.C.: Federal Highway Administration. Final Report, June 1976.

26. Weesner, J. F., Meyerkord, K.M. "Pilot Bus Priority System for Urban Arterials." Transportation Frontiers for the Next Millennium: 69th Annual Meeting of the Institute of Transportation Engineers. Las Vegas, Nevada. Aug 1-4, 1999. pp. 12.

27. King County Metro. Final Report: Rainier Avenue South Transit Signal Priority Field Evaluation. Jan 2001.

28. User's Manual for SCRITS. Science Applications International Corporation.

http://plan2op.fhwa.dot.gov/toolbox/scrits_manual.pdf

APPENDIX A
BSP Spreadsheet
(Disk Attached)

ANALYSIS OF BUS PRIORITY SYSTEMS		
	User Input	Calculated Value
Date of analysis		11/29/2001
Scenario		Alternative 1
Analyst		Chada
Description of improvement		Bus priority on 10 miles of arterial X
PRE-IMPLEMENTATION CHECKLIST		
	YES or NO	
Express bus service?	yes	
Express bus service during off peak?	yes	
Farside bus stops?	yes	
Highly saturated cross streets over 1.0 v/s ratio?	yes	
Heavy volume intersections in the network?	yes	
Many instances of two transit vehicles approaching one intersection?	yes	
Do you have AVL technology installed?	no	
Priority recommended?		
Additional recommendations:		Active Priority Not As Beneficial
BUS OPERATIONS, WEEKDAY ONLY		
Miles on which priority treatment is implemented	10	
Number of buses per weekday on priority routes	64	
Current average bus speed on arterials (mph)	15	
Percentage of bus travel time attributable to signal delay	25%	
Estimated % reduction in signal delay from pre-emption	40%	
Average minutes per mile for buses without priority		4.00
Average minutes per mile for buses with priority		3.60
Average bus speed with priority (mph)		16.67
Percentage increase in bus speed		11.1%
Number of route-hours saved per day		4.3
Number of route-hours saved per year, weekdays only		1067
Number of daily passengers on affected routes	1,800	
Average passenger trip length (miles)	5	
Person hours without priority, weekday only		600
Person hours with priority, weekday only		540
Savings in person hours per weekday		60
Savings in person hours per year, weekdays only		21,900
Elasticity of demand with respect to bus speed	0.3	
Estimated increase in average weekday passengers on route		60
Daily vehicle trips on corridor served by bus route(s)	25,000	
Percent reduction in vehicle trips in bus corridor		0.24%
Annual value of time savings for bus passengers		\$240,900
TRAFFIC OPERATIONS		
Weekday daily volume of cross street traffic for entire route	50,000	
Percentage of traffic that incurs pre-emption delay	10%	
Average delay time per pre-empted vehicle (sec.)	12	
Additional vehicle hours delay per day to cross street traffic		17
Additional person hours delay per day		22
Additional person hours delay per year		7,908
Annual value of vehicle passenger time savings, weekdays only		-\$113,089
COSTS AND BENEFITS		
Total of bus passenger and vehicle passenger time savings		\$127,811
Installation cost	\$500,000	
Service life (years)	10	
Annual operating/maintenance cost	\$50,000	
Operating cost per bus route-hour	\$40	
Annual bus operating cost savings		\$42,667
Annualization factor		0.142
Total annualized cost		\$78,333
Annualized benefits (weekday only) minus annualized cost		\$49,478
Benefit/cost ratio weekday only		1.6
INTERSECTION SPECIFIC GUIDELINE		
	INPUT	SUGGESTED METHOD
Enter saturation level here for specific intersection	1.2	Priority May Not Be Effective