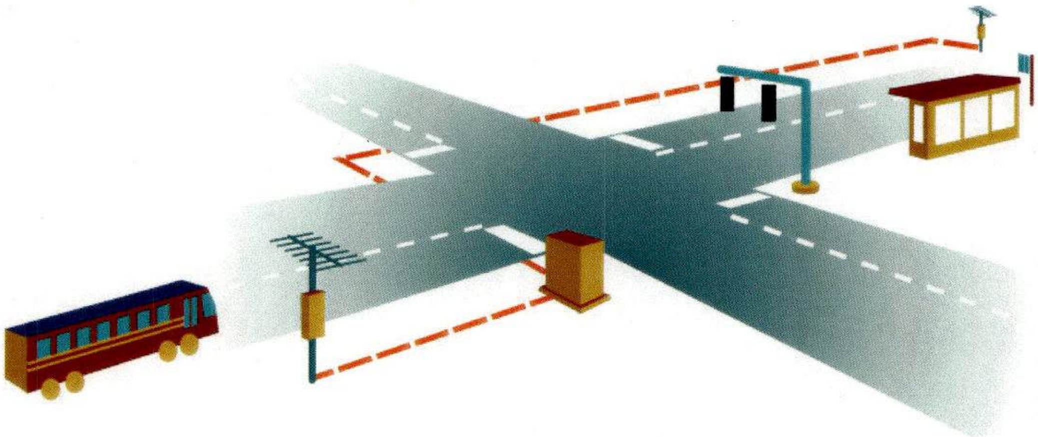
Transit Signal Priority System Performance Monitoring and Optimization
for
King County Department of Transportation Metro Transit Division



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Washington State Transportation Center

DISCLAIMER

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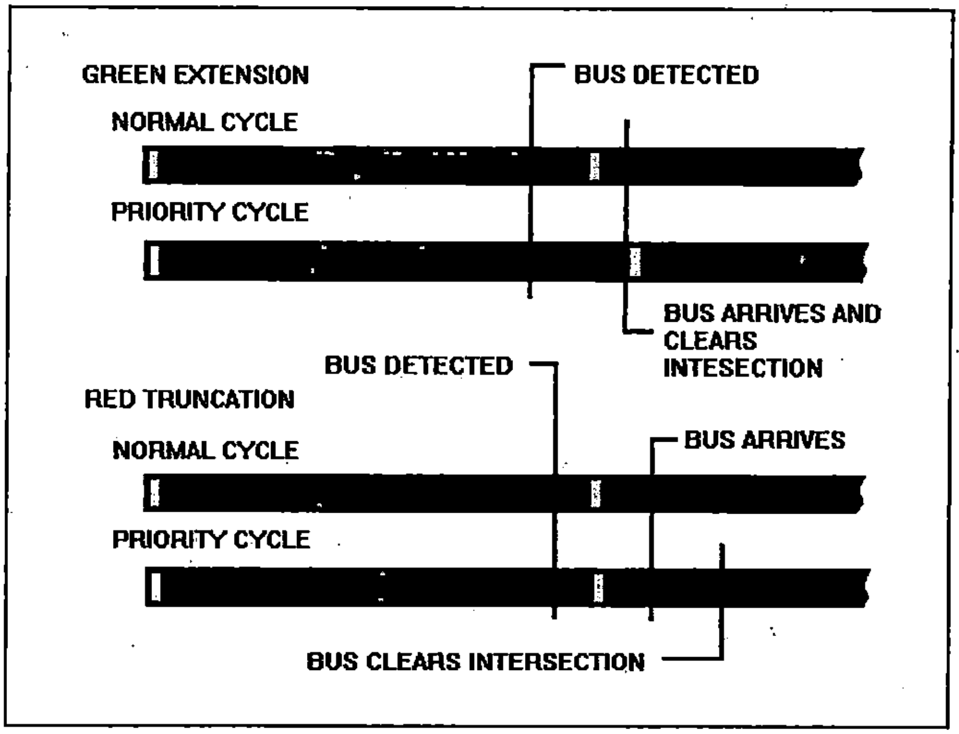
EXECUTIVE SUMMARY

Transit Signal Priority (TSP) is one of several strategies being implemented by King County Metro Transit to improve customer service and increase fleet efficiency. Specifically, TSP systems are designed to improve schedule adherence (on-time performance) and decrease travel time, by limiting, or even avoiding, the time that buses spend stopped at traffic signals.

TSP can improve customer satisfaction by reducing signal-related stops for a smoother ride, reducing signal-related delay for a faster trip, and reduce travel time variability for improved on-time performance. The operational efficiency benefits of TSP include shorter travel times and decreased travel time variability, which help reduce scheduled running times, and the ability to speed up late buses, helping to minimize service disruptions. Significant reductions in travel time may decrease the number of buses required to provide service on a route, or may allow existing vehicle resources to accommodate reduced speed attributable to increased congestion.

To make the best use of TSP technology, it is important to monitor how well the system is working and what impact it is having. In the case of TSP, not only do decision-makers within the transit agency have a vested interest in the performance of the system, but those in traffic jurisdictions do as well.

KC Metro Transit's TSP system is designed to provide selected buses with extra "green time" (an extended green signal or an early green signal by truncating the red signal phases) to generate travel time and reliability benefits for transit services. For traffic jurisdictions, allocating green time at individual intersections, and within a network of intersections, requires balancing the needs of general traffic, pedestrians, and emergency vehicles with the desire to provide TSP benefits to transit. In a coordinated signal system, providing additional green time for one traffic movement necessarily reduces green time for an opposing movement, as shown in the diagram below.

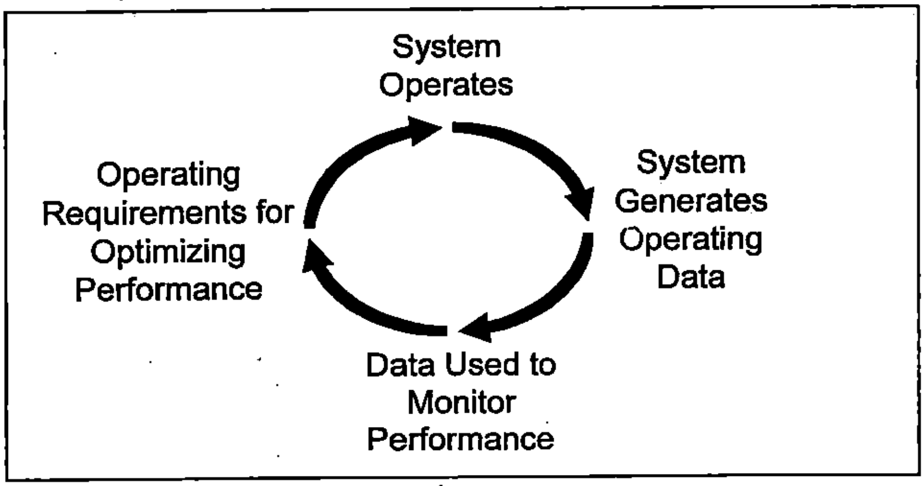


Green Extension and Red Truncation TSP Strategies

To minimize the impact of TSP on cross-street traffic, traffic jurisdictions limit access to this extra green time in a variety of ways. In King County, the City of Seattle sets the minimum interval between transit priority requests, as well as the specific priority control strategy (how the signal controller will respond to a priority request). The use of automatic vehicle identification (AVI) technology allows KC Metro Transit to specify which buses take advantage of opportunities to request priority.

MONITORING TSP PERFORMANCE

Ongoing monitoring of standard TSP performance measures provides a tool for comparing the performance of multiple TSP intersections and corridors, and for analyzing the potential benefits of implementing additional TSP corridors. By monitoring the extent to which TSP benefits are realized, agencies can adjust operational strategies to maximize the effectiveness of the system, as depicted in the feedback loop below.



TSP Performance Feedback Loop

Demonstrating the performance of TSP to partner traffic jurisdictions is essential. The focus here is on monitoring and reporting the transit benefits of TSP, not on determining the traffic impact of TSP. Often the lack of understanding of the transit benefits of TSP contributes to unwillingness on the part of traffic engineers to implement TSP.

Two types of information are available for monitoring, measuring and optimizing TSP performance: operating data and data about the environment in which the TSP system is operating. Information from these two sources is then fused to create TSP "events." Operating data come from logs created by the automatic vehicle identification (AVI) subsystem (the Transponder Log) and the transit priority request (TPR) subsystem (the Operations Log) at each TSP-equipped intersection. Additional operational information not currently available from the TSP system comes from the automatic vehicle location system and the automatic passenger counter system. "Environment" data refers to information about the more static elements of the TSP environment, specifically traffic signal settings and transit service route and schedule information. Data from these sources are fused together to create intersection event logs and corridor event logs.

PERFORMANCE MEASURES

The objective of the performance monitoring methodology is to summarize, on an ongoing basis, the overall performance of the TSP system in meaningful and manageable ways. Specific performance measures need to be useful for managing the TSP system, determining the impact of changes in strategy, and assessing the impact of the system on transit operations. Most importantly, these performance measures need to clearly communicate the benefits of TSP to traffic jurisdiction decision-makers, as well as to KC Metro Transit staff, management, and policy board members. The proposed performance measures include measures of efficiency (how well the limited resource of access to green time is being used) and effectiveness (how well the system is producing the desired effects and benefits). The specific recommended performance measures are shown in the following table, along with their respective TSP Objective.

TSP Objectives and Performance Measures

Objective	Performance Measure	Intersection Level	Corridor Level
Efficiency			
Use available opportunities to make requests for priority.	% Eligible Trips Receiving TSP Benefit	X	X
	% Late Trips Receiving TSP Benefit	X	X
	% Priority Requests Providing Benefit	X	
	Allowed Priority Requests Per Hour	X	
Effectiveness			
Reduce transit vehicle signal delay for as many passengers as possible	Number of Passengers Receiving TSP Benefit	X	X
	Passenger Delay Reduction	X	X
Reduce vehicle travel time in a corridor	Time Saved Per Trip Receiving TSP Benefit	X	X
	Delay Reduction as % of Corridor Travel Time for Trips Receiving TSP Benefit		X
Improve transit service reliability	% Late Trips Receiving TSP Benefit that Recover to On-Time		X
	Corridor On-Time Performance for Trips with TSP Benefit		X
Reduce number of signal-related stops for as many people and buses as possible	Number of Passenger Stops Avoided	X	X
	Number of Stops Avoided by Buses	X	X
Reduce running time variability.	Standard deviation of corridor travel time		X

TSP BENEFITS

Optimizing TSP performance requires taking a closer look at the benefits associated with TSP objectives. It is not a matter of trading off benefits between traffic operations and transit operations. Typical traffic engineering practice is to optimize vehicle flow, generally irrespective of vehicle occupancy. As a result, traffic jurisdictions seek to minimize the impact of TSP actions on traffic flow by setting constraints on the operation of the TSP system (such as a maximum number of calls for priority within a certain time period). The primary benefits of TSP are not mutually exclusive; that is to say that achieving one benefit does not preclude the opportunity to achieve another. The degree to which each benefit can be maximized, though, is constrained by the TSP technology and traffic jurisdiction policy.

The primary TSP benefits, and their implications for operating strategy, are described below. The first four are customer service related and the last three are related to operational efficiency.

Customer Satisfaction Benefits

1. **Improve customer satisfaction with comfort by reducing the number of signal-related stops whenever possible.** Constant stopping and starting at bus stops and traffic signals can be uncomfortable and annoying for bus passengers. Signal-related stops are avoided only if a bus clears an intersection on a green extension. Without TSP treatment the bus would have to stop at a red light and wait for a green light. An early green reduces signal delay but does not reduce signal-related stops. This benefit applies to both express and local service. The fewer the stops for the greatest number of people, the greater the benefit. This is a relatively low value benefit of TSP. (Some minimal brake maintenance benefits are also associated with reducing the number of signal-related stops.)

2. **Improve customer satisfaction with service reliability by speeding up trips operating behind schedule whenever possible.** Service that is running behind schedule creates anxiety for waiting passengers. It also contributes to a late arrival

at a destination and an increased likelihood of missed connections at transfer points. It is a great benefit to customers to minimize the occurrence of late buses or to minimize the degree to which buses are late. This benefit applies only to local service, since there is no such thing as "behind schedule" for express service. The higher the number of passengers on late buses that receive priority treatment, the greater the benefit.

3. **Improve customer satisfaction with convenience by speeding up express trips whenever possible.** Express service appeals to customers because the travel time is more commensurate with traveling in a car. The shorter the travel time, the more attractive the service. TSP provides the opportunity to minimize travel time in a corridor. This benefit only applies to express service because local service is constrained by schedule requirements. The more express service passengers that receive priority treatment, the better. This benefit has a moderate value to customers because it is intermittent.

4. **Improve customer satisfaction with convenience by reducing <u>scheduled</u> travel time.** Convenience is increased for customers if the scheduled travel time is reduced. This benefit is possible only if the scheduled running time for specific trips can be reduced in anticipation of consistent access to signal priority treatment. This benefit applies to local service only because express service is not constrained by a schedule. For customers, this is a moderately high value benefit because it provides a consistently shorter travel time. (Related operations benefits are discussed below.)

<u>Operational Efficiency Benefits</u>

1. **Reduce service disruptions by speeding up late trips whenever possible.** Operations managers are continually juggling resources to accommodate service disruptions. A mechanical breakdown, for instance, requires that a replacement bus and driver be dispatched to the appropriate location to fill as many scheduled trips as possible. Late buses also create service disruptions that need to be

managed by operations staff if they are severe enough. The more late buses that receive priority treatment, the better. This benefit applies only to local service and has moderately low benefit to operations because it is unlikely that TSP can address severely late service.

2. **Reduce <u>scheduled</u> pay-hours for recovery time and running time by reducing running time variability.** If TSP helps to consistently reduce the variability of running times, it may be possible to reduce scheduled running times and recovery times at the end of the line to reflect increased confidence in travel time estimates. This benefit is possible only if specific trips consistently receive priority treatment. The value of this benefit is high for operations because it can reduce current or future payhours associated with providing the service. This benefit is applicable to both local and express service. The more trips with less variability, the higher the benefit.

3. **Reduce current (or future) vehicle and pay-hour costs by reducing <u>scheduled</u> running times.** If signal delay savings achieved with TSP can be reflected in reduced scheduled running time, it may be possible to reduce the cost of providing the service in terms of payhours and vehicle requirements. More likely is that these efficiencies will allow current resources to accommodate future conditions that otherwise would have required increases in payhours or vehicles to provide the same level of service. The operations value of this benefit is very high because of its potential to save costs. This benefit applies to both local and express service. The more trips with consistent access to priority treatment, the higher the benefit.

<u>OPERATING STRATEGIES</u>

The benefits identified above result from four basic operating strategies. These four strategies are identified below:

Strategy A

Give buses priority whenever possible, unless the bus is ahead of schedule. This strategy moderately improves customer comfort by reducing the number of signal-related stops whenever possible. Some minimal maintenance cost reduction is also possible because of reduced wear on braking systems.

Strategy B

Give priority to express trips whenever possible. This strategy moderately increases customer convenience by reducing travel time for express trips whenever possible.

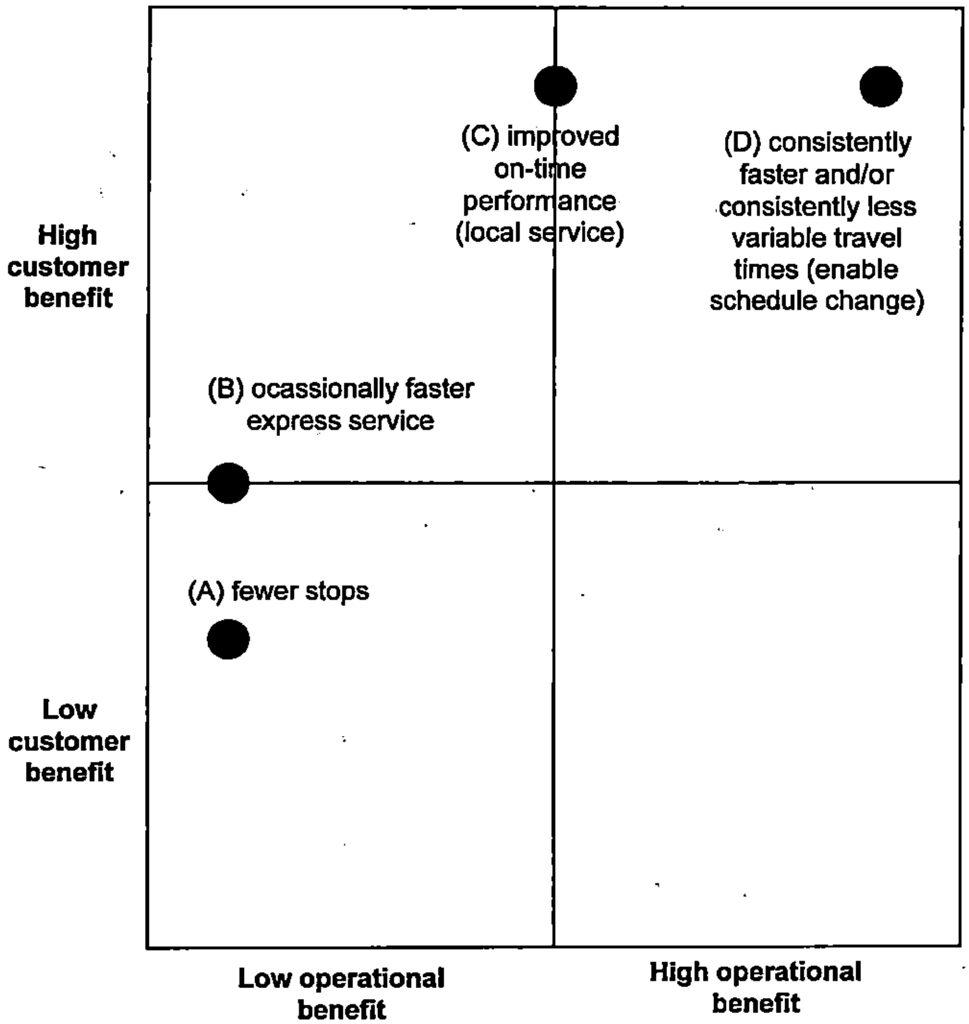
Strategy C

Give priority to buses that are behind schedule whenever possible. This strategy greatly improves customer satisfaction with service reliability by improving on-time performance. Moderate operational benefits also result from this strategy in the form of fewer service disruptions due to late buses.

Strategy D

Always give priority to specific trips unless ahead of schedule. This strategy enables schedule changes that reflect shorter travel times, and it provides the highest customer satisfaction and operational efficiency benefits. Customer convenience is improved with a shorter scheduled travel time. Operational benefits include reduced scheduled pay-hours for recovery time and running time because of less running time variability, and reduced current (or future) vehicle and pay-hour costs because of shorter scheduled running times.

The figure below shows a comparison of the customer service and operational efficiency values of each of the four basic strategies.



Operating Strategies and TSP Benefits

CONCLUSIONS

The ability to effectively implement the higher priority operating strategies is currently constrained either by technology or policy. For example, the initial deployment does not provide a way for the TPR subsystem to know how full or how late a bus is. As a result, eligibility tables must accommodate a desire to give priority to late and full trips by identifying trips that are typically late or full. Optimizing this benefit would require access to "real time" schedule performance and passenger load information, a possibility with the emergence of "smart bus" technology. The analysis above indicates that a priority should be placed on accessing real-time schedule adherence information in order to maximize TSP benefits.

Maximizing TSP benefits requires working within the policy constraints of multiple traffic jurisdictions. These constraints are designed to provide green time advantages to transit, without unduly interfering with the flow of vehicles on the arterial network. The greatest TSP benefits to the transit agency are those that deliver operational efficiency and therefore reduce costs. In order to achieve these benefits at all, the operational strategies must enable schedules to reflect signal delay savings and reduced running time variability. That is, schedule makers can shorten scheduled running times knowing that signal priority treatment will be available to specific trips. The agency may gain far more benefit by identifying a limited number of "eligible" trips so as to guarantee that those trips receive priority than by pursuing strategies that provide more buses with priority but result in a lower value benefit to the agency.

SECTION 1: INTRODUCTION

King County Metro Transit is in the process of implementing a transit signal priority (TSP) system in cooperation with several traffic jurisdictions. Initially, 26 intersections in two corridors heavily used by transit will be equipped with TSP as a way of providing "green time" advantages to transit services.

As with other investments of this magnitude, it is important to monitor how well the system is working, what impact it is having, and how to make the best use of the technology. In the case of TSP, not only do decision-makers within the transit agency have a vested interest in the performance of the system, but those in traffic jurisdictions do as well.

This document has two purposes. The first is to present the reporting requirements for ongoing performance monitoring of the TSP system in King County. The second purpose is to present strategies for optimizing that performance.

TSP Benefits

TSP is one of several strategies for improving transit services and increasing fleet efficiency at the corridor level. Specifically, TSP is designed to improve schedule adherence and decrease travel time by limiting, or even avoiding, time spent stopped at traffic signals.

For the average rider, TSP should create a better trip experience by shortening trip times, reducing the number of stops and starts, and increasing schedule reliability (better on-time performance). These features increase the attractiveness of transit as a transportation alternative, theoretically resulting in increased ridership, public support, and revenue.

Decreased travel time, of significant enough magnitude, may have immediate benefits in terms of allowing fewer buses to provide the same level of service. However, it is more likely that TSP will defer schedule maintenance, that is, reduce the need to add time and buses to counteract the effects of increasing congestion.

Performance Monitoring

The TSP system is designed to provide selected buses with extra "green time" (an extended green signal or an early green signal) to generate travel time and reliability benefits for transit services. By monitoring the extent to which these benefits are realized, agencies can adjust operational strategies to maximize the effectiveness of the system. Ongoing monitoring of standard performance measures also provides a tool for comparing the performance of multiple TSP intersections and corridors and for analyzing the potential benefits of implementing additional TSP corridors.

For traffic jurisdictions, allocating green time at individual intersections, and within a network of intersections, requires balancing the needs of general traffic, pedestrians, and emergency vehicles with the desire to provide TSP benefits to transit. In a coordinated signal system, providing additional green time for one traffic movement necessarily reduces green time for an opposing movement. To minimize the impact of TSP on cross-street traffic, traffic jurisdictions limit access to this extra green time in a variety of ways. In King County, the City of Seattle sets the minimum interval between transit priority requests, as well as the specific priority control strategy (how the signal will respond to the priority request). The use of automatic vehicle identification (AVI) technology allows KC Metro Transit to specify which buses may take advantage of opportunities to request priority. By monitoring how efficiently access to priority is used, operational strategies can be modified to improve the efficiency of the TSP system. This feedback loop is depicted in Figure 1.

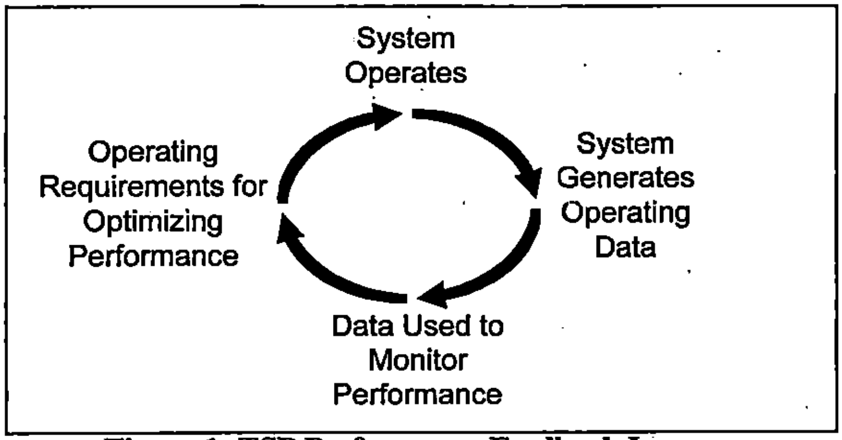


Figure 1: TSP Performance Feedback Loop

Demonstrating the performance of TSP to partner traffic jurisdictions is essential. The focus here is on monitoring and reporting the transit benefits of TSP, not on determining the traffic impact of TSP. Often the lack of understanding of the transit benefits of TSP contributes to unwillingness on the part of traffic engineers to implement TSP.

A successful methodology for ongoing TSP performance monitoring needs to provide the answers to two important questions in a manageable and meaningful way:

- How **effectively** is the system realizing the anticipated benefits of TSP?
- How **efficiently** is the opportunity to request priority being used?

Performance Optimization

KC Metro Transit's job is to determine, given technological capabilities and local jurisdiction requirements, the best use of its limited access to requests for priority. The current configuration relies on setting certain transit vehicle trips as "eligible" to request priority treatment. Future enhancements may allow information about service route, passenger load and on-time status to more directly influence which vehicles actually request priority.

Optimizing the performance of the system requires answering these questions:

- Given current constraints of the TSP system, how can KC Metro Transit get the most benefit from a limited set of allowed requests for signal priority?
- Looking toward the future, what changes in the configuration of the system would generate the most improvement in the performance of the system?

Organization of the Report

The next section of the report provides background about TSP as it is implemented in King County. Section Three describes the data sources and data fusion requirements. Section Four presents measures for ongoing monitoring of TSP performance, and in Section Five, the nature of TSP benefits is discussed along with strategies to optimize those benefits.

SECTION 2: BACKGROUND

KC Metro Transit's TSP system combines on-board and roadside technologies that detect buses within the flow of traffic, communicate information from the buses to the roadside, and for buses that meet certain criteria, send requests for priority to the traffic signal controller.

This section provides a brief overview of KC Metro Transit's TSP system as it relates to performance monitoring and optimization.

SYSTEM COMPONENTS

As implemented in King County, TSP involves three closely related subsystems. Two are operated by KC Metro Transit: the AVI subsystem and the transit priority request (TPR) subsystem. Various traffic jurisdictions operate the third, traffic signal control (TSC) subsystems. Figure 2 provides an overview of the on-site components of the TSP system.

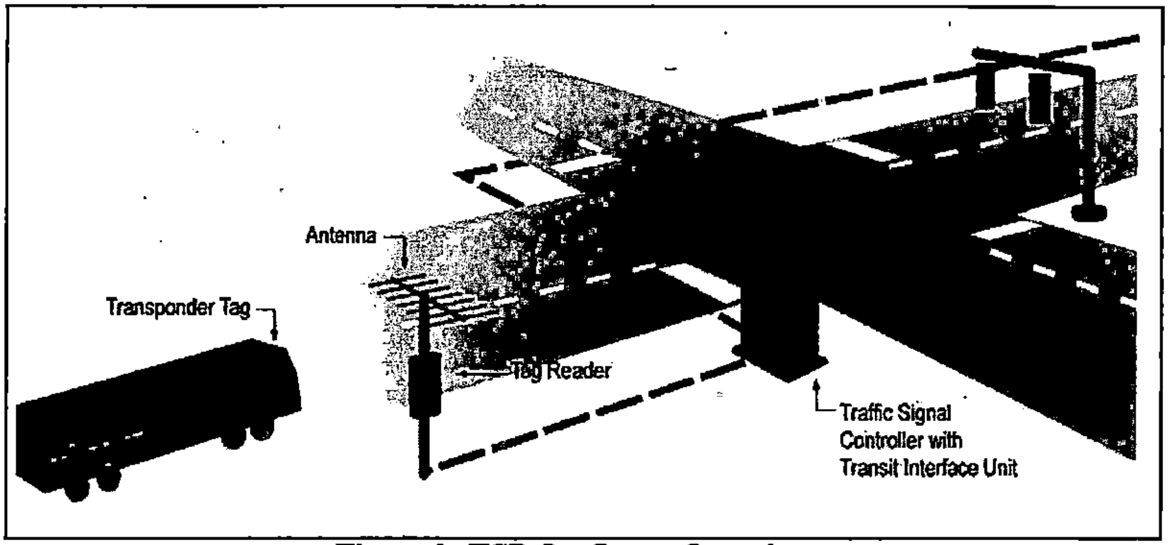


Figure 2: TSP On-Street Overview

Automatic Vehicle Identification Subsystem

The AVI system detects buses within the traffic flow, gathers information about those buses and passes the information on to the TPR system. Buses are equipped with an Amtech radio frequency (RF) transponder tag mounted on the upper right front corner of the bus as shown in Figure 3. The tag contains static data such as agency and vehicle ID number, and dynamic data such as driver number and current route/run assignment. As part of normal operations, drivers enter this dynamic data on the radio system keypad at the beginning of each day's work. The dynamic data are then passed to the transponder tag by the tag interface unit (TIU).

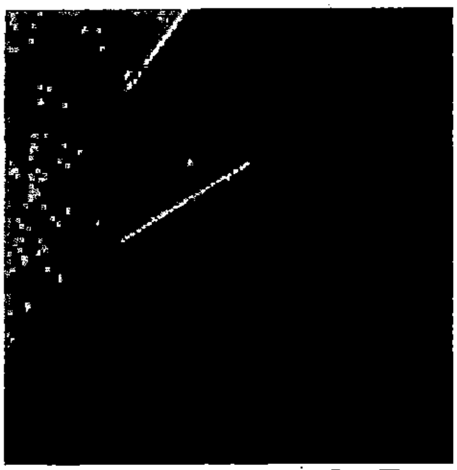


Figure 3: Transponder Tag

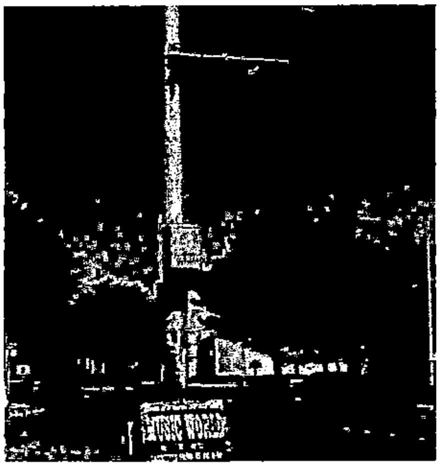


Figure 4: Antenna and Tag Reader

The roadside antenna and tag reader unit (shown in Figure 4) interrogates the transponder tag as the bus passes by. The antenna and tag reader unit is generally located 500 to 1000 feet before the intersection. A Lonworks Communication Network is used to carry valid AVI data from the tag reader to the TPR Generator located in the signal controller cabinet.

Transit Priority Request Subsystem

The TPR system consists of TPR generators, located in the signal controller cabinet at each intersection equipped for TSP (see Figure 5), and a central TPR server that provides connectivity for the TPR field equipment. The TPR generator determines whether a bus is eligible for priority by comparing the AVI tag reads to a list of buses (designated by route/run assignment number) identified as "eligible."[1] After a bus has been determined as eligible for priority, the TPR generator checks the minimum interval for priority requests and if the minimum interval has passed since the last request was made, the TPR generator issues a request for priority to the TSC subsystem. Figure 6 provides an overview of this process.

Transponder Logs created by the AVI system and Operations Logs from the TPR system are accessed through the TPR server. These daily logs are the primary sources of data for calculating performance measures.

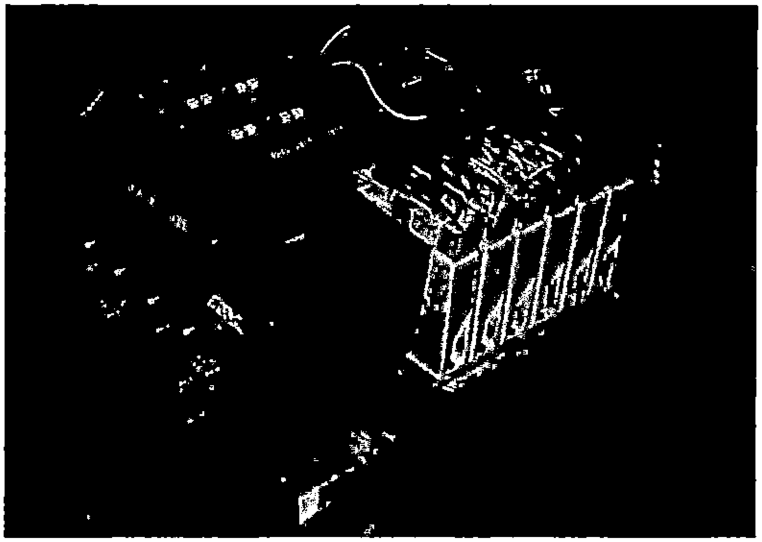


Figure 5: TPR Generator

[1] KC Metro Transit identifies the specific transit trips (currently defined by route/run and time of day) that are "eligible" for priority as a way to ensure that the trips that are most likely to benefit from priority treatment get any available chances of priority. Future enhancements to the system may allow for other strategies for determining which buses receive priority treatment. Specifically, access to real-time information about on-time status and current passenger load would significantly refine how requests for priority are managed.

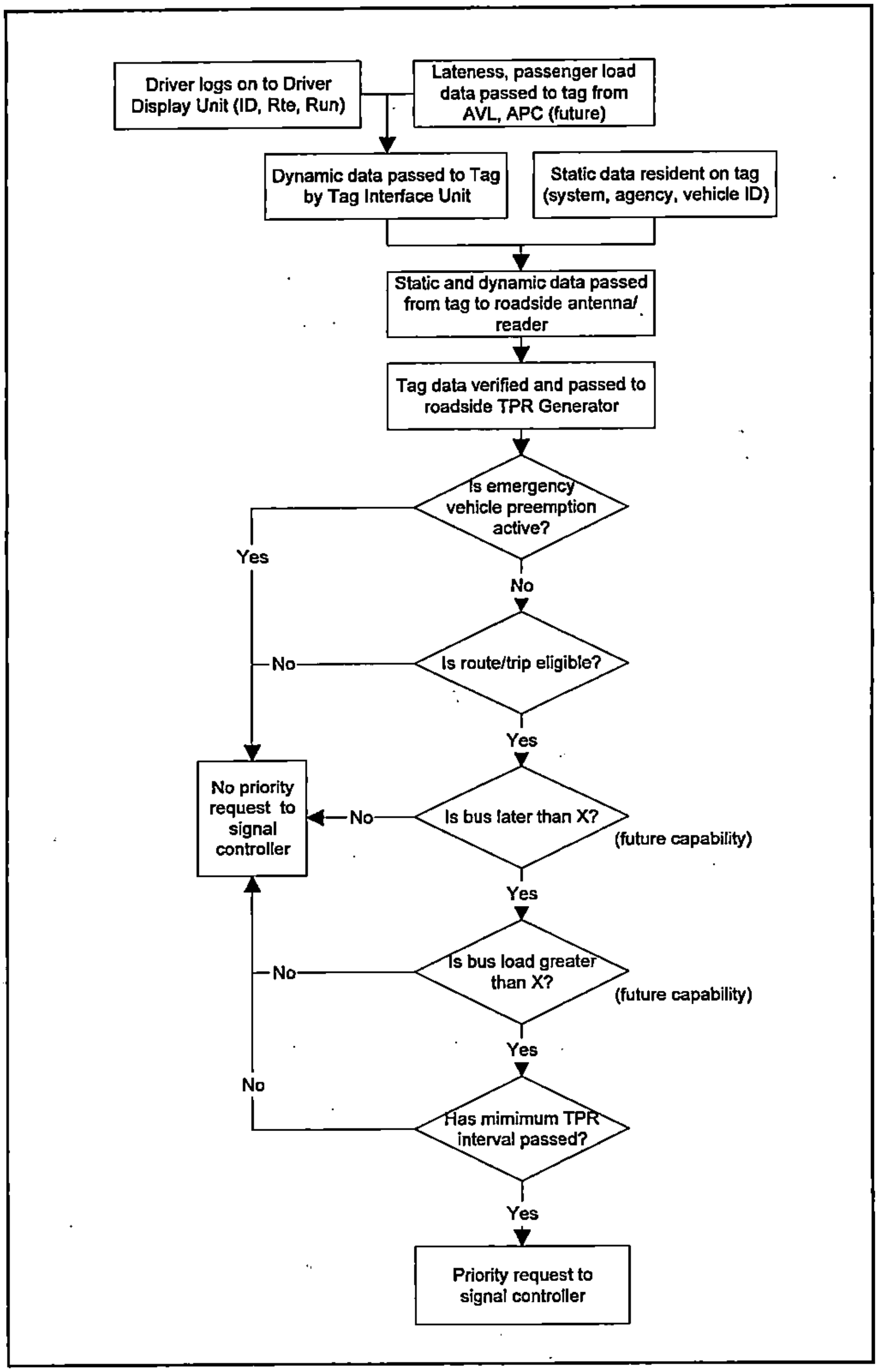


Figure 6: Transit Priority Request Process

Traffic Signal Control Subsystem

The TSC, operated by the traffic jurisdiction, is used to implement all TSP control strategies consistent with the traffic jurisdiction's signal operating policy and goals. These strategies control whether and how a signal will respond to a transit priority request. For example, the City of Seattle has implemented TSP control strategies according the following requirements (see Figure 7):

- Traffic signals shall extend their green interval for approaching priority vehicles. This gives the bus an opportunity to clear the intersection without stopping.
- Traffic signals shall shorten red displays for approaching priority vehicles. Although the bus still stops at the signal, it is for a shorter period of time.
- Traffic signals shall not shorten any minimum or clearance intervals.
- Traffic signals shall not skip any phases.
- Traffic signals shall not break coordination.

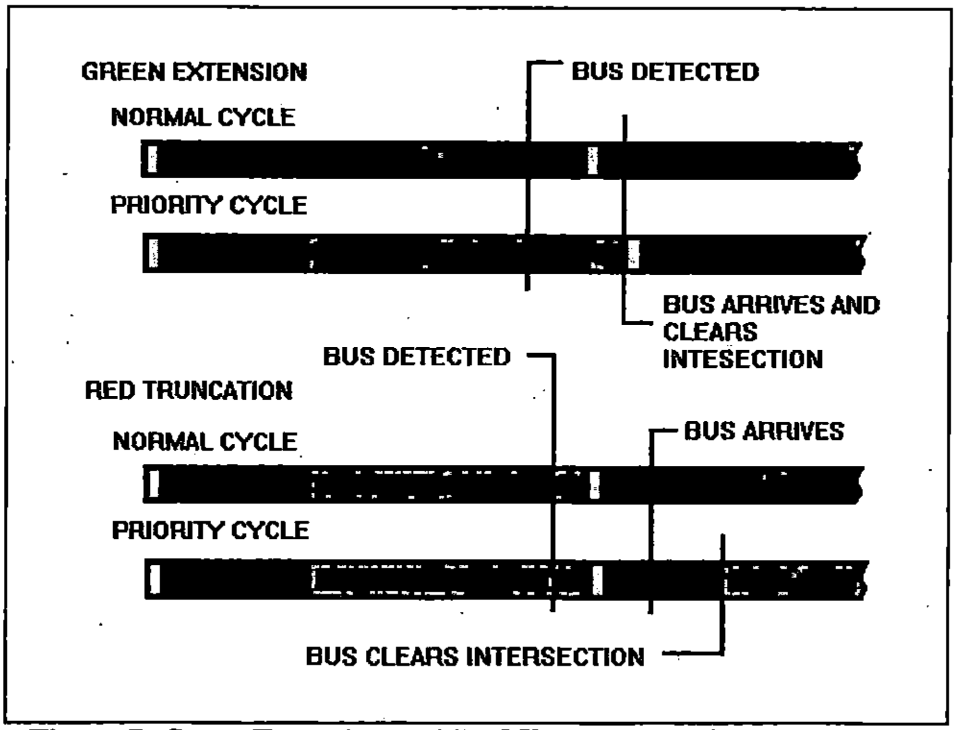


Figure 7: Green Extension and Red Truncation TSP Strategies

SECTION 3: DATA SOURCES AND DATA PREPARATION

Two types of information are available for monitoring, measuring and optimizing TSP performance: operating data and data about the environment in which the TSP system is operating. Information from these two sources is then fused to create TSP "events." Figure 8 shows the relationship of the operating data, environment data and fused data.

Operating data come from logs created by the AVI (Transponder Log) and TPR (Operations Log) subsystems at each TSP-equipped intersection. Additional operational information not currently available from the TSP system comes from the automatic vehicle location (AVL) system and the automatic passenger counter (APC) system.

"Environment" data refers to information about the more static elements of the TSP environment, specifically traffic signal settings and transit service route and schedule information.

Data from these sources are fused together to create intersection event logs and corridor event logs. It is important to note that the performance monitoring methodology presented here is derived from available automated data sources (field equipment) and not from actual field observations.

Detailed information about the data used to generate the performance measures will be presented in this section. This section begins with some definitions that are key to understanding and using TSP data.

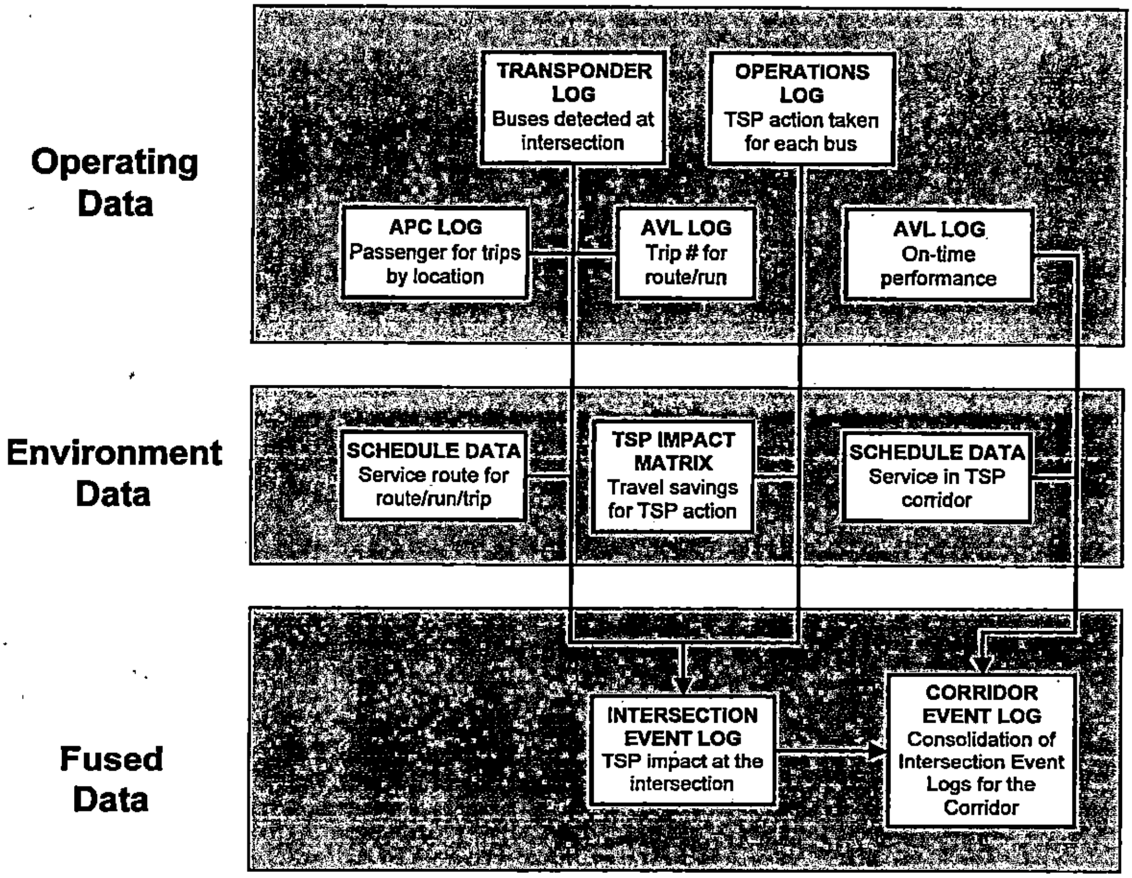


Figure 8: Performance Data Sources Overview

DEFINITIONS

The following attributes of transit service must be accommodated in the design of TSP performance monitoring and measurement.

Service route The term "service route" refers to the route number that passengers are familiar with on bus destination signs, bus stop signs, and timetables. This is not necessarily the same as the route number in the route/run combination. In some cases service route numbers may also include a letter that passengers are not accustomed to seeing. For example, service route 7 is divided into 7N, providing service north of downtown Seattle, and 7S, providing service south of downtown. For reporting purposes, service on the 7

Express cannot be combined with service on the 7S local. More importantly, the route number in the route/run combination cannot be used to determine service route.

Route/run The route number / run number combination identifies the specific trips operated by one vehicle for a particular service day, from the time the bus leaves the garage until the time it returns, regardless of how many operators have driven it. These trips may or may not be on the service route that matches the route number in the route/run combination. In TSP data and scheduling data the route number and run number are in separate fields. "Route" should not be assumed to be "service route" unless it is stated as such. For reporting purposes, summarizing by route/run is not useful in any meaningful way.

Trip number In combination with the route/run number and service day, the trip number uniquely identifies a specific trip on a specific service route. This is not a round trip but a trip from one end of the route to the other. In the case of service route 7S, for example, there are northbound trips and southbound trips. To complicate matters, the trip number used in the schedule database is not the same as the trip number in the AVL database. The scheduling trip number is one number less than the AVL trip number. Scheduled travel time varies by time of day; therefore, for reporting purposes, trips from different times during the day may or may not be comparable.

Service days Transit service is categorized as Weekday, Saturday or Sunday service. Weekday service on a given route is the same Monday through Friday (unless special extra trips are added). Sunday service schedules are run on holidays. Route/run numbers and trip numbers do not mean the same thing for Weekday, Saturday and Sunday service. Service operating after midnight is associated with the day on which the vehicle left the garage. All reporting needs to be limited to a specific service day.

Service changes

KC Metro Transit adjusts its transit schedules three times each year, generally in February, June, and September. It cannot be assumed that route/run numbers and trip numbers (and in some cases service route numbers) refer to the same transit service from one service change to the next. Any reporting must be within the confines of a single service change. Service route and schedule data from previous service changes must be saved if TSP data from that same service change will be analyzed.

Timepoints

Timepoints refer to specific locations at which a scheduled arrival or departure time has been set for a particular service route. Bus drivers are held accountable for arriving or departing from timepoints "on time." "On time" is generally defined as 0 to 5 minutes after the scheduled time. Service routes are defined by a series of timepoints, although there can be variations within service routes. In the Rainier Avenue corridor, for example, service route 7 uses timepoints at South Graham Street, Genessee Street, McClellan Street and South Jackson Street, as does service route 9. The 7 Express, however, uses these same timepoints with the exception of McClellan Street. Geographically these timepoints are at the center of the intersection, not at bus stops. Scheduled arrival times at locations other than timepoints can only be interpolated.

Time of day For comparison and analytical purposes it is useful to divide the service day into segments reflecting changes within which TSP is operating. For instance, there is generally less transit service and less congestion in the midday (from about 9:00 AM to 3:30 PM). During morning and evening peak times (6:00 AM to 9:00AM and 3:30 PM to 6:30 PM), travel patterns and volumes vary depending on the primary flow of traffic. For performance reporting purposes, the boundaries of these time of day periods should match other reporting within the agency.

OPERATING DATA

Transponder Log (*.av)

Information collected and recorded by the readers at TSP intersections comes from the transponder tags mounted on buses. These electronic tags contain static information about the vehicle and dynamic information about the service being operated by the bus. As the bus approaches the intersection, the tag is interrogated by the antenna and tag reader. Each intersection approach for which TSP is enabled has its own reader. For instance, the intersection of Genessee and Rainier has a reader for northbound buses and a reader for southbound buses.

Transponder Log data fields are shown in Table 1. These fields are only relevant to KC Metro Transit tags.

Table 1: Transponder Log Data Fields

Field	Data Element	Description
1	Date	The date that the tag was read by the reader.
2	Time	The time that the tag was read by the reader, in military time with hours, minutes and seconds, comes from the reader itself.
3	Reader	Four-digit number assigned to each reader, comes from the reader itself.
4	System	Identifier for operators of tag.
5	Agency	Additional identifier for operators of tag equipped vehicles, numeric. King County KC Metro Transit = 1, comes from static information resident on the tag.
6	Vehicle ID	Number painted on the bus, three or four digits, comes from static information resident on the tag.
7	Operator ID	Number assigned to the bus driver, comes from dynamic information on the tag, entered by the bus driver.
8	Route	One- to three-digit number that, in combination with the run number, identifies the trips to be operated by a vehicle on a particular service day, comes from dynamic information on the tag, entered by the bus driver.
9	Run	One- to three-digit number that, in combination with the route number, identifies the trips to be operated by a vehicle on a particular service day, comes from dynamic information on the tag, entered by the bus driver.
10	Trip	One- to two-digit number that identifies the trip being operated, currently not available from the tag.
11	Class	Currently not used.
12	Late	Currently not used, intended to eventually indicate the on-time status of the vehicle.
13	Riders	Currently not used, intended to eventually indicate the passenger load of the vehicle.

Operations Log (*.op)

Tag reads that have been verified by the reader are passed to the TPR generator for TSP action. For the Operations Log, the TPR generator records all transit requests for priority and indicates whether the result was a priority request to the signal controller, the signal phase at the time of the request, and the next signal phase. The Operations Log also includes denied requests for priority and the reason that the request was denied. Operations Log data fields are shown in Table 2.

Table 2: Operations Log Data Fields

Field	Data Element	Description
1	Date	The date that the TPR generator received the priority request.
2	Time	The time that the TPR generator received the priority request, in military time with hours, minutes and seconds; comes from the TPR itself.
3	TPR number	Four-digit number assigned to each TPR generator; comes from the TPR itself.
4	Reader	Four-digit reader number identifying which reader the transaction was initiated by.
5	Request?	Y for priority request made to controller, N for no priority request,
6	No call reason	Reason given for no priority request (frequency, eligibility, time of day)
7	Activation time	Time the TPR request was activated.
8	Activation phase	Phase during which the TPR request was activated.
9	Change time	Time of the phase change following the TPR request
10	Change phase	Phase to which the signal changed following the TPR request.

Automatic Vehicle Location Log (*.txt)

The AVL Log is a text file created by the AVL system specifically to meet the needs of the TSP system. The file includes the AVL data for timepoints relevant to the TSP system.

Because trip number currently is not available from the TSP transponder tag (and therefore, service route cannot be known), this AVL file is used to determine trip numbers, which are then entered into the Intersection Event Log. AVL Log data fields are shown in Table 3.

Table 3: AVL Log Data Fields

Field	Data Element	Description
1	Date	The date the data were collected.
2	Time	The time the vehicle encountered the timepoint based on route mapping information.
3	TPID	The timepoint identification number.
4	VID	Number painted on the bus, three or four digits.
5	Route	One- to three-digit number that, in combination with the run number, identifies the trips to be operated by a vehicle on a particular service day.
6	Run	One- to three-digit number that, in combination with the route number, identifies the trips to be operated by a vehicle on a particular service day.
7	Trip	One- to two-digit number that identifies the trip being operated. This number is generated by the AVL system and is not the same as the trip number generated by the scheduling system.
8	Dir	Direction of the current trip as defined by the scheduling system.
9	OID	Number assigned to the bus driver, comes from dynamic information on the tag, entered by the bus driver.

Automatic Passenger Counters File

Data from the APC system are based on samples of trips in previous service changes. Data elements include average passenger load approaching each intersection for each trip. Because the data are tied to trips in previous service changes, the use of the route/run/trip designation is not necessarily consistent with the current service change. Passenger load data are applied to trips on the basis of time of day. They can only serve as an estimate of the likely passenger load based on past ridership records. APC data fields are shown in Table 4.

Table 4: APC Data Fields

Field	Data Element	Description
1	Zone #	Bus stop identification number
2	Trip #	Trip identification number
3	# Observ	Number of observations in the sample
4	Time MPM	Time in minutes past midnight
5	Time Clock	Time of day
6	Load Appr	Average number of passengers on board the bus as it approached the stop for the sample observations
7	Ons	Average number of passengers getting on board the bus at the stop for the sample observations
8	Offs	Average number of passengers getting off the bus at the stop for the sample observations
9	Route	Service route
10	Part	For through-routed routes, the part of the route as designated by N for North, S for South, W for West and E for East
11	Service	Variation in service route
12	IB/OB	Inbound or outbound

ENVIRONMENT DATA

Schedule Data

These data provide the service route designation for a given service day/route/run/trip and direction combination. Data extracted from the schedule database (specifically the Distribution Database or DDB) are shown in Table 5.

Table 5: Schedule Data Fields

Field	Data Element	Description
1	Service Route	Route number that appears on the bus destination sign and timetables
2	Service Day	Weekday, Saturday, or Sunday
3	Route	One- to three-digit number that, in combination with the run number, identifies the trips to be operated by a vehicle on a particular service day.
4	Run	One- to three-digit number that, in combination with the route number, identifies the trips to be operated by a vehicle on a particular service day.
5	Scheduling Trip Number	Trip number from scheduling system, not the same as trip number from AVL system
6	Direction	Direction of the current trip as defined by the scheduling system.

TSP Impact Matrix

The performance monitoring methodology currently relies on the assumption that the limited information available from the TPR Operations Log provides a "good enough" estimate of the likely impact of signal priority treatment for each vehicle making a priority request at an intersection. Future enhancements to the TSP equipment may make determining the TSP impact much more straightforward.

Currently, the only information available from the TPR Log about signal behavior following a priority request is the phase during which the request was activated, how long it took for the signal to change to the next phase, and what that next phase was.

The TSP Impact Matrix reflects specific control strategies. Given information about the operation of the signal with and without TSP, a matrix can be set up for each direction (for which TSP is activated) at each intersection. The matrix establishes the relationship between the variables that can be known from the TPR Log and the result of a priority request. The TSP Impact Matrix will vary by intersection and time of day. It will change if signal timing or TSP control strategies change.

As the system is currently configured, requests for transit priority can be made even when no TSP benefit is possible. Hardware and software strategies are being explored to limit the number of non-beneficial priority requests. TSP actions can be categorized as follows:

No priority request

- No request because of time of day
- No request because of eligibility
- No request because of frequency

Beneficial request

- Clear on green extension
- Early green - 2 short phases
- Early green - 1 short phase

No impact request

- Clear without a green extension
- No priority possible (less than minimum phase length remaining)

Looking at detailed signal timing plan and TSP strategies can aid in estimating the value of a request at any point in the cycle. However, the time into the cycle that a request was made is currently not available. Further analysis, detailed in the Appendix, allows an estimate of the TSP action and corresponding delay reduction using only the information currently available from the Operations Log. For example, at Rainier and Genessee, if a midday priority request is made during Phase 3G, and the signal changes to Phase 1 in less than 15 seconds, the TSP result will be an early green with Phase 1 shortened to the minimum duration. Table 6 shows the TSP Impact Matrix values for the example described in the Appendix.

It is far more desirable to be able to directly determine the TSP action and delay reduction from the operating logs. Future enhancements to the system are likely to result in this ability.

Table 6: Sample TSP Impact Matrix

Time of Day	Activation Phase	Activation to change (sec)	TSP Action	Delay reduction (sec)	Stop Avoided (Y/N)
AM Peak	1G	27-31	None	0	N
AM Peak	1G	26	Extended Green	49	Y
AM Peak	1G	21-25	Extended Green	49	Y
AM Peak	1G	16-20	Extended Green	0	N
AM Peak	1C	1-4	Early Green	18	N
AM Peak	2G	12	Early Green	5-18	N
AM Peak	2G	5-11	Early Green	5	N
AM Peak	2G	1-4	Early Green	2-5	N
AM Peak	2C	3	Early Green	1	N
AM Peak	2C	1-2	Early Green	0	N
AM Peak	3G	1-11	None	0	N

FUSED DATA

The equipment logs and environment data are fused to create an Intersection Event Log and a Corridor Event Log. The Intersection Event Log has a record for every trip for which the vehicle was detected. The Corridor Event Log aggregates the data from each of the Intersection Event Logs and creates a record for every trip that uses the entire corridor.

Intersection Event Log

Two important things have to happen in creating the Intersection Event Log. The first is the assignment of a service route to each trip record. This information is currently not available from the Transponder Log and must be added to the record from the AVL Log or the Schedule Data.

The second important step is to match the Transponder Log records to the Operations Log record in order to create a complete picture of what happened to each bus at the intersection. This is done by matching the time records in each log.

The record layout of the Intersection Event Log is shown in Table 7.

Table 7: Intersection Event Log Fields

Field	Data Element	Source
1	TPR Number (location)	TPR log
2	Reader Number (direction)	Reader log
3	Date	TPR log/Reader log
4	Service Day	Calculated
5	Time	Reader log
6	Time of Day	Calculated
7	Agency	Reader log
8	Vehicle	Reader log
9	Rte/run	Reader log
10	Trip	Reader log
11	Service Route	Reader log
12	Eligible (Y, N)	Eligibility Table
13	Schedule Arrival	Schedule data
14	Schedule Status	Calculated
15	Passenger Load	APC log
16	No- request reason	TPR log
17	Activation time	TPR log
18	Activation phase	TPR log
19	Change time	TPR log
20	Change phase	TPR log
21	Time from Activation to Change	TPR log
22	TSP Action	TSP Impact Matrix
23	Delay Reduction	TSP Impact Matrix
24	Stops Avoided	TSP Impact Matrix

Corridor Event Log

The Corridor Event Log combines information from the Intersection Event Logs for the intersections that are used by service routes operating in a specific corridor. This log creates a record of the impact of TSP at one or more intersections used by a route. Figure 9 shows the TSP-equipped intersections in the Rainier corridor. Four service routes use the Rainier corridor: 7, 7Express, 9, and 39Express.

The record layout of the intersection event log is shown in Table 8.

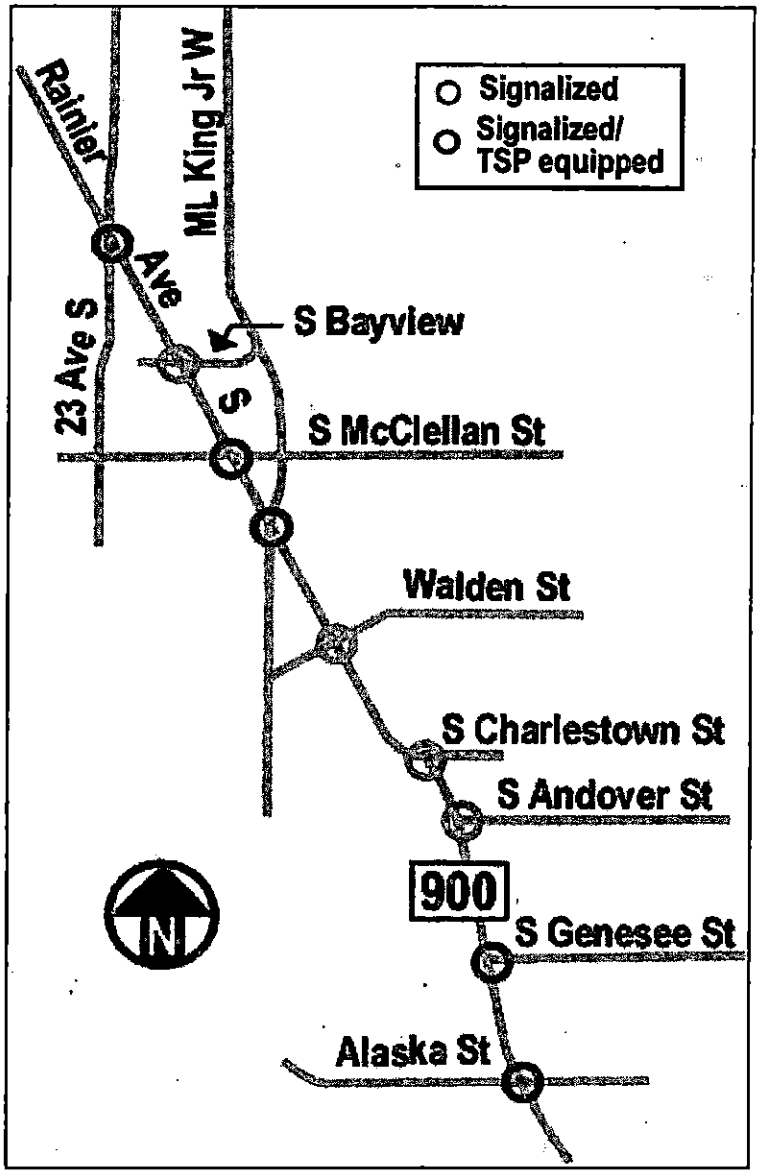


Figure 9: Rainier Avenue South Corridor

Table 8: Corridor Event Log Fields

Field	Data Element	Source
1	Agency	Intersection Event Logs
2	VID	Intersection Event Logs
3	Route	Intersection Event Logs
4	Run	Intersection Event Logs
5	AVL trip #	Intersection Event Logs
6	Service Route	Intersection Event Logs
7	Eligible (Y, N)	Intersection Event Logs
8	Scheduled Time at Beginning Timepoint	Schedule Data
9	AVL Time at Beginning Timepoint	AVL Log
10	Schedule Status Beginning Timepoint	Calculated
11	Reader Time at 1st intersection	Intersection Event Log
12	Delay Reduction at 1st intersection	Intersection Event Logs
13	Stops Avoided at 1st intersection	Intersection Event Log
14	Passenger Load at 1st intersection	Intersection Event Log
15	Reader Time at 2nd intersection	Intersection Event Logs
16	Stops Avoided at 2nd intersection	Intersection Event Log
17	Delay Reduction at 2nd intersection	Intersection Event Log
18	Passenger Load at 2nd intersection	Intersection Event Logs
19	Reader Time at 3rd intersection	Intersection Event Log
20	Delay Reduction at 3rd intersection	Intersection Event Logs
21	Stops Avoided at 3rd intersection	Intersection Event Logs
22	Passenger Load at 3rd intersection	Intersection Event Logs
•	•	•
•	•	•
•	•	•
23	Schedule at Ending timepoint	Schedule Data
24	AVL time at Ending timepoint	AVL log
25	Schedule Status at Ending timepoint	Calculated
26	Scheduled Corridor Travel Time	Calculated
27	Total Delay Reduction	Calculated
28	Total Stops Avoided	Calculated

SECTION 4: PERFORMANCE MONITORING

The objective of the performance monitoring methodology is to summarize, on an ongoing basis, the overall performance of the TSP system in meaningful and manageable ways. Specific performance measures need to be useful for managing the TSP system, determining the impact of changes in strategy, and assessing the impact of the system on transit operations. Most importantly, these performance measures need to clearly communicate the benefits of TSP to traffic jurisdiction decision-makers, as well as to KC Metro Transit staff, management, and policy board members. The proposed performance measures include measures of efficiency (how well the limited resource of access to green time is being used) and effectiveness (how well the system is producing the desired effects and benefits).

The performance reporting methodology is designed to determine the benefits of TSP to transit operations, not the impact TSP has on traffic operations.

This section presents performance measures and reporting designed to monitor the performance of the TSP system at both the intersection level and the corridor level. The reports are parameter driven and designed to support a variety of special analyses.

The selected performance measures are those that provide the most meaningful assessment of the TSP system for a variety of audiences. For example, County Council members are likely to be interested in the number of transit passengers benefiting from TSP in a corridor, whereas the traffic engineer from a participating jurisdiction may be more interested in the percentage of late vehicles receiving a TSP benefit at an individual intersection. TSP project management staff will be interested in the average number of priority requests allowed per hour at an individual intersection, and transit agency management will want to know the percentage of corridor travel time reduction made possible by TSP. Figure 10 provides an overview of the entire performance monitoring strategy.

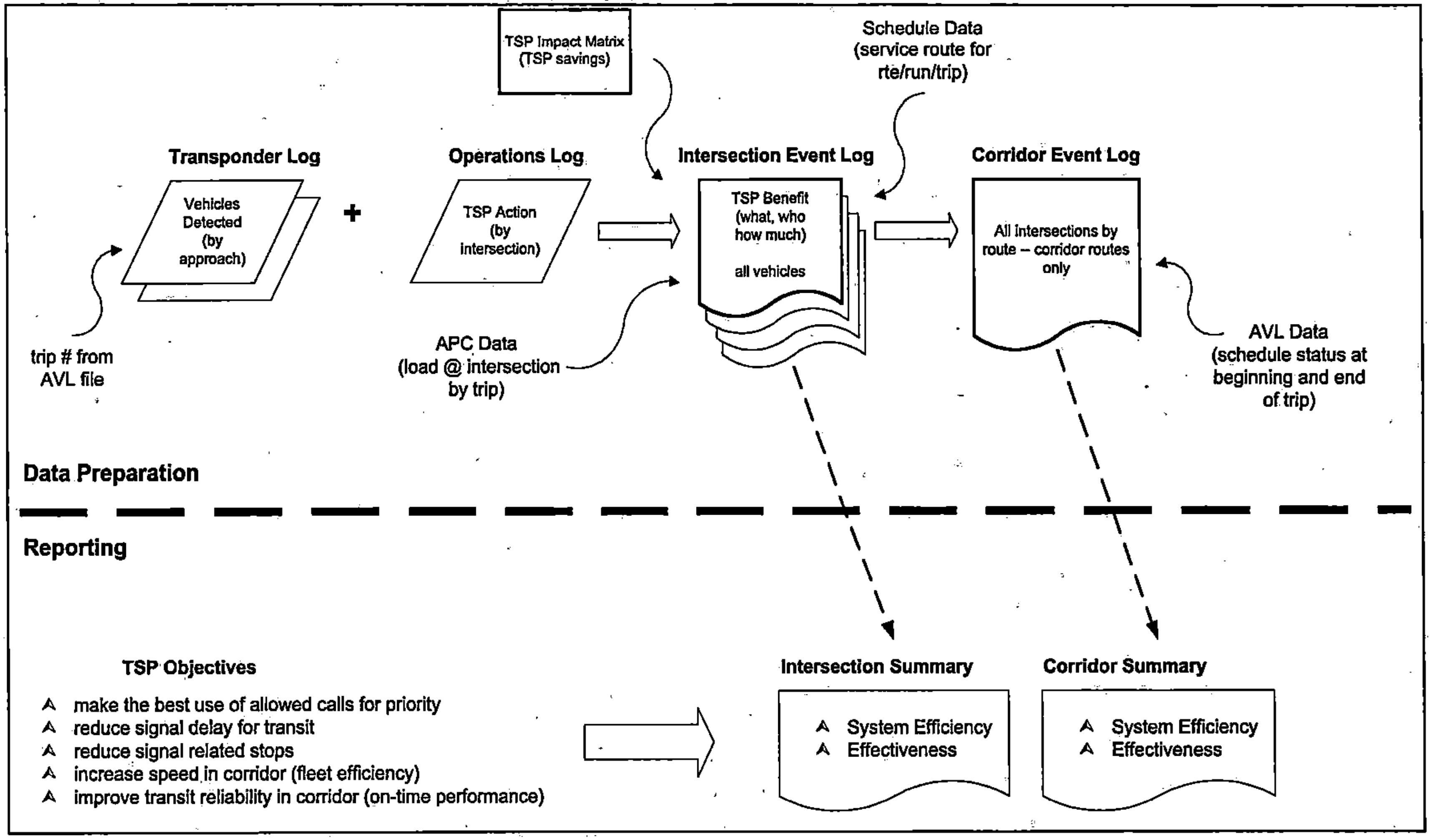


Figure 10: Overview of TSP Performance Monitoring Process

The remainder of this section introduces the performance measures, their relationship to specific TSP objectives, and descriptions of the intersection and corridor level performance reporting[2].

OBJECTIVES AND PERFORMANCE MEASURES

Twelve performance measures, four for efficiency and eight for effectiveness, have been identified. Each is directly tied to one of the six TSP objectives described below. Table 9 summarizes the correlation between each performance measure and the TSP objectives. Table 9 also indicates whether the measure applies to intersection level reporting, corridor level reporting, or both. Each of the performance measures is discussed later in this section.

Efficiency Objective

- Use available opportunities to make requests for priority. The traffic jurisdiction limits access to extra green time by limiting the number and frequency of requests for priority. It is KC Metro Transit's objective to use as many of these opportunities for requesting priority as possible in order to maximize the benefits of TSP to the transit agency.

Effectiveness Objectives

- Reduce transit vehicle signal delay for as many passengers as possible. In taking advantage of opportunities to request priority for buses, KC Metro Transit's objective is to use those opportunities when the most passengers will benefit.
- Reduce vehicle travel time in a corridor. Reducing signal-related delay at multiple intersections within a corridor reduces the total transit travel time for the corridor. If these travel time reductions are significant enough to reduce

[2] All numbers used in this section are hypothetical. Not enough data have been available to prepare and fully test these reports.

scheduled running time, or reduce the need to add running time to accommodate increased congestion, the cost of providing service is reduced.

- Improve transit service reliability. On-time performance can be improved if vehicles that are running behind schedule are able to take advantage of TSP signal-delay reductions.
- Reduce number of signal-related stops for as many people and buses as possible.
- Reduce running time variability. The more variable a trip running time is, the longer the scheduled running time needs to be to accommodate most of the possible running time lengths. Sometimes additional recovery time is required at the end of a trip to accommodate longer than average running times. By reducing signal-related delay, KC Metro Transit's objective is to reduce the variability of running times so that schedules can more accurately reflect expected on-street conditions.

Table 9: TSP Objectives and Performance Measures

Objective	Performance Measure	Intersection Level	Corridor Level
Efficiency			
Use available opportunities to make requests for priority.	% Eligible Trips Receiving TSP Benefit	X	X
	% Late Trips Receiving TSP Benefit	X	X
	% Priority Requests Providing Benefit	X	
	Allowed Priority Requests Per Hour	X	
Effectiveness			
Reduce transit vehicle signal delay for as many passengers as possible	Number of Passengers Receiving TSP Benefit	X	X
	Passenger Delay Reduction	X	X
Reduce vehicle travel time in a corridor	Time Saved Per Trip Receiving TSP Benefit	X	X
	Delay Reduction as % of Corridor Travel Time for Trips Receiving TSP Benefit		X
Improve transit service reliability	% Late Trips Receiving TSP Benefit that Recover to On-Time		X
	Corridor On-Time Performance for Trips with TSP Benefit		X
Reduce number of signal-related stops for as many people and buses as possible	Number of Passenger Stops Avoided	X	X
	Number of Stops Avoided by Buses	X	X
Reduce running time variability.	Standard deviation of corridor travel time		X

MEASURES OF EFFICIENCY

The four measures of efficiency are described below. These measures indicate how efficiently the resource (opportunities to request priority) is being used to get the desired result (beneficial priority requests).

1. Measure: Percentage of Eligible Trips Receiving TSP Benefit

Description: This measure indicates the relationship between trips that are eligible to receive TSP benefits and those trips that actually do receive TSP benefits. A low percentage would indicate the need to develop strategies to provide TSP benefits to more buses or to refine the criteria for eligibility. Currently, eligible trips are determined in advance, but future enhancements to the system will identify eligible trips as they approach the intersection on the basis of current passenger load and schedule adherence information. This measure applies at both the intersection and corridor levels. At the corridor level, a trip would be defined as receiving a TSP benefit if the trip received priority treatment at a minimum of one intersection in the corridor.

Calculation: Number of trips with delay reduction > 0 divided by total number of eligible trips.

2. Measure: Percentage of Late Trips Receiving TSP Benefit

Description: This measure indicates how well the TSP system is addressing the needs of late trips, for many traffic jurisdictions a key criterion for making extra green time available. A "late trip" is one that is operating behind schedule (according to agency set standards) at the timepoint just before the beginning of the TSP corridor. This measure includes all late trips regardless of whether they are "eligible" for TSP. This measure applies at both the intersection and corridor levels.

Calculation: Number of late trips (late at intersection or timepoint before the corridor begins) with delay reduction > 0 divided by total number of late trips.

3. Measure: Percentage of Priority Requests Providing Benefit

Description: As the system is currently configured, not all allowed priority requests result in a delay reduction for a bus granted priority (the bus clears the intersection without using the needing the extended green time). This measure will reflect improvements in the efficiency with which the currently configured system operates. This measure is useful for monitoring performance at individual intersections.

Calculation: Number of trips with delay reduction > 0 divided by total number of priority requests to the controller.

4. Measure: Priority Requests Per Hour

Description: Some traffic jurisdictions set a minimum interval for priority requests. For example, a priority request may be allowed only after five minutes have passed since the last priority request was allowed. Depending on the headways of buses using the TSP corridor, not all priority request opportunities may be used. This measure indicates the average number of requests that are actually being allowed. A low number could indicate the need to decrease the minimum interval. An increase in this number would indicate that the priority request resource is being better utilized. This measure is useful at the intersection level.

Calculation: Total number of priority requests to the controller divided by number of hours. (Could also be presented as priority requests per hour divided by maximum allowable requests per hour as an indicator of utilization.)

MEASURES OF EFFECTIVENESS

The eight measures of effectiveness are described below. These measures indicate how well the system is producing the desired effects of increased speed and reliability for the most transit passengers.

1. **Measure:** Number of Passengers Receiving TSP Benefit

Description: This measure indicates how effective the system is at delivering TSP benefits to the most number of people, for many traffic jurisdictions a key criterion for making extra green time available. This measure applies to both intersection and corridor level reporting. At the corridor level a trip would be defined as receiving a TSP benefit if the trip received priority treatment at a minimum of one intersection in the corridor.

Calculation: Total number of passengers on trips with delay reduction > 0. For a corridor the number of passengers is an average of the number of passengers on board at each intersection for which delay reduction > 0.

2. **Measure:** Passenger Delay Reduction (passenger-hours)[3]

Description: This measure is the overall delay reduction multiplied by the number of passengers experiencing that delay reduction. Although not particularly meaningful in and of itself, this measure provides a good way to compare the performance of several intersections (or corridors), or the performance of one intersection (or corridor) over time.

Calculation: Number of passengers on board at each intersection where delay reduction > 0 times the amount of delay reduction at that intersection. For a corridor, the totals from each intersection are added together.

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[3] A key concept is the distinction between reporting travel time savings and delay savings. Travel time reduction in the corridor is not measured directly because scheduled timepoints may induce bus drivers to slow down to avoid being early at a timepoint. Therefore, overall travel time won't necessarily reflect delay reductions due to TSP. Instead, the delay reductions experienced at each intersection are added together as an indicator of the potential travel time reduction, which may or may not have been realized.

3. **Measure:** Time Saved per Trip Receiving TSP Benefit

Description: This measure indicates the average time saved by each vehicle receiving TSP benefits. It is useful as a comparison to expected time savings, as well as for cost benefit analyses and programming for future TSP investments. This measure applies to both the intersection and corridor levels. At the corridor level a trip would be defined as receiving a TSP benefit if the trip received priority treatment at a minimum of one intersection in the corridor.

Calculation: Total delay reduction divided by number of trips with delay reduction > 0.

4. **Measure:** Delay Reduction as a Percentage of Corridor Travel Time for Trips Receiving TSP Benefit

Description: This measure indicates the relative size of the delay reduction in comparison to travel time in the entire corridor. This measure is very sensitive to the definition of the extent of the TSP corridor.

Calculation: Total delay reduction for all trips divided by total travel time for all trips with delay reduction > 0.

5. **Measure:** Percentage of Late Trips Receiving TSP Benefit that Recover to On-Time

Description: This measure is an indicator of the value of TSP in helping late trips regain on-time status. These are trips that are late at the timepoint just before the TSP corridor and on-time at the timepoint at the end of the TSP corridor.

Calculation: Number of late trips (late at the timepoint before the beginning of the TSP corridor) with delay reduction > 0 that are on-time at timepoint following TSP corridor divided by total number of late trips with delay reduction > 0.

6. Measure: <u>Corridor On-Time Performance for Trips with TSP Benefit</u>

Description: This measure reflects the ability of TSP to maintain on-time performance in a corridor. It measures the on-time performance of trips at the timepoint directly following the TSP corridor.

Calculation: Number of trips with delay reduction > 0 that are on-time at timepoint following TSP corridor divided by the total number of trips with delay reduction > 0.

7. Measure: <u>Number of Passenger Stops Avoided</u>

Description: This measure is the number of signal-related stops that have been avoided multiplied by the number of passengers who avoided those stops. This measure is meaningful at both the intersection and corridor levels.

Calculation: Number of passengers on board at each intersection where a stop was avoided times the number of stops avoided at that intersection. For a corridor, the totals from each intersection are added together.

8. Measure: <u>Standard Deviation of Corridor Travel Time</u>

Description: This measure indicates the amount of variation in travel time along a corridor. This measure is only meaningful at the corridor level and only meaningful for comparing the trips that occur at the same time of day.

Calculation: Standard deviation of the difference between the Reader Time at last intersection and Reader Time at first intersection from the Corridor Event Log.

INTERSECTION AND CORRIDOR LEVEL REPORTING

TSP performance can be summarized at both the intersection and corridor levels. Most of the performance measures are most meaningful at the corridor level; however intersection level reporting can be very important for operational analysis.

The Intersection Summary report is designed to be specific to a single intersection, although it may contain multiple directions of travel and multiple time periods. It can include all trips using that intersection, regardless of whether they use the entire corridor.

The Corridor Summary report aggregates the TSP benefits for all the intersections in a corridor. This is the level at which TSP benefits are expected to be maximized. The Corridor Summary report includes only trips for routes running the entire length of the corridor.

Reporting parameters for the Intersection Summary and Corridor Summary reports include the following:

- Direction -- northbound, southbound, eastbound, westbound, or all (all not an option for corridor level reporting)
- Intersection (or Corridor) -- intersection as defined by four-digit TPR number, corridor as defined by TSP project team
- Service route -- Service route number
- Service day -- Weekday, Saturday or Sunday
- Time of day -- AM Peak (6:00 AM - 9:00 AM), Midday (9:00 AM - 3:30 PM), PM Peak (3:30 PM - 6:30 PM) for weekday service, no time of day selections for Saturday and Sunday service. All day is (6:00 AM - 6:30 PM) Weekday, Saturday and Sunday.
- Date range -- restricted to Weekday, Saturday or Sunday service days within the date range. Date ranges cannot overlap service change date boundaries.

Table 10 presents a summary of the data elements, data sources and calculations for the Intersection Summary report. The performance measures discussed above are highlighted.

Table 10: Intersection Summary Report Data Sources and Calculations

Data Element	Source	Calculation
Number of eligible trips	Intersection Event Log	Count by time period
Number of late trips	Intersection Event Log	Count by "schedule status" > 5 min
Extended Green	Intersection Event Log	Count by TSP Action
Early Green - 1 short phase	Intersection Event Log	Count by TSP Action
Early Green - 2 short phases	Intersection Event Log	Count by TSP Action
Extended Green w/o benefit	Intersection Event Log	Count by TSP Action
No TSP possible	Intersection Event Log	Count by TSP Action
Total allowed priority requests	Calculated	Total of the above
Trips receiving TSP benefit	Intersection Event Log	Total number of trips with positive "delay reduction"
% Eligible trips receiving TSP benefit	Intersection Event Log	Total number of trips where "eligible" is Y and "delay reduction" is > 0 divided by total number of trips where "eligible" is Y.
% Late trips receiving TSP benefit	Intersection Event Log	Total number of trips where "schedule status" is > 5 minutes and "delay reduction" > 0 divided by total number of trips where "schedule status" > 5 minutes
% Priority requests providing benefit	Calculated	"trips receiving TSP benefit" divided by "total allowed priority requests"
Allowed priority requests per hour	Calculated	"total allowed priority requests" divided by number of hours in reporting period
No request because of frequency	Intersection Event Log	Count by 'no request reason"
No request because of eligibility	Intersection Event Log	Count by 'no request reason"
Priority requests denied	Calculated	Total of above 2 items
Total delay reduction (minutes)	Intersection Event Log	Total of "delay reduction" for time period converted to minutes
Passengers receiving TSP benefit	Intersection Event Log	Total "passengers" for all trips where "delay reduction" is >0
Passenger delay reduction (passenger hours)	Calculated	Total "passengers receiving TSP benefit" times "total delay reduction" converted to hours
Time saved per trip receiving TSP benefit	Calculated	"Total delay reduction" divided by "trips receiving TSP benefit"
Passenger Stops Avoided	Intersection Event Log	Total of "yes" entries for stop avoided times number of "passengers" for trips where stop avoided is "yes".

Figures 11, 12 and 13, show that pie charts and bar charts can be used to display some of the information in the Intersection Summary report. All numbers are hypothetical.

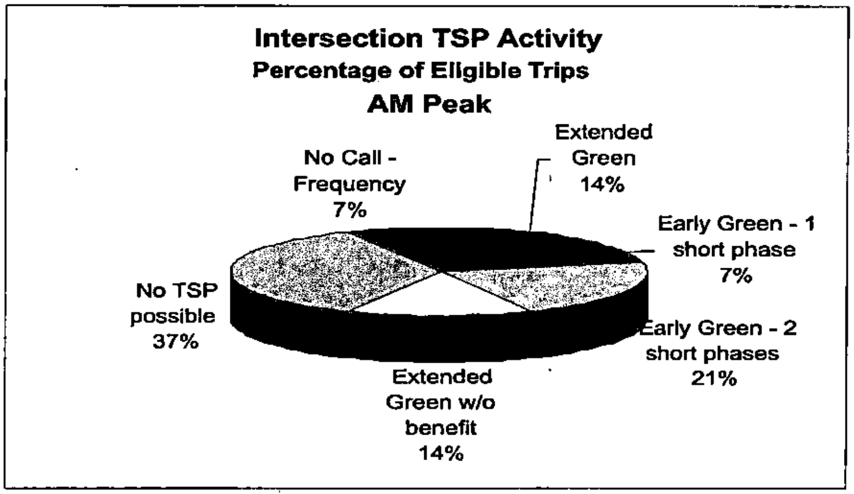


Figure 11: Intersection TSP Activity Pie Chart

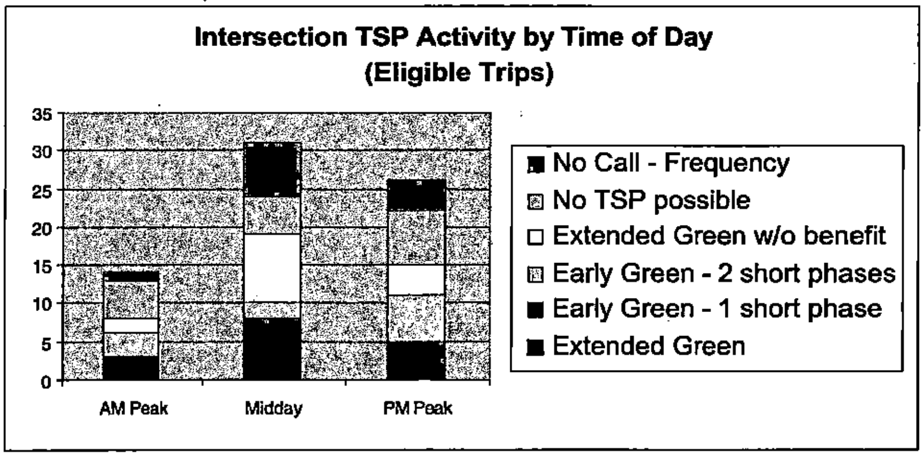


Figure 12: Intersection TSP Activity Bar Chart

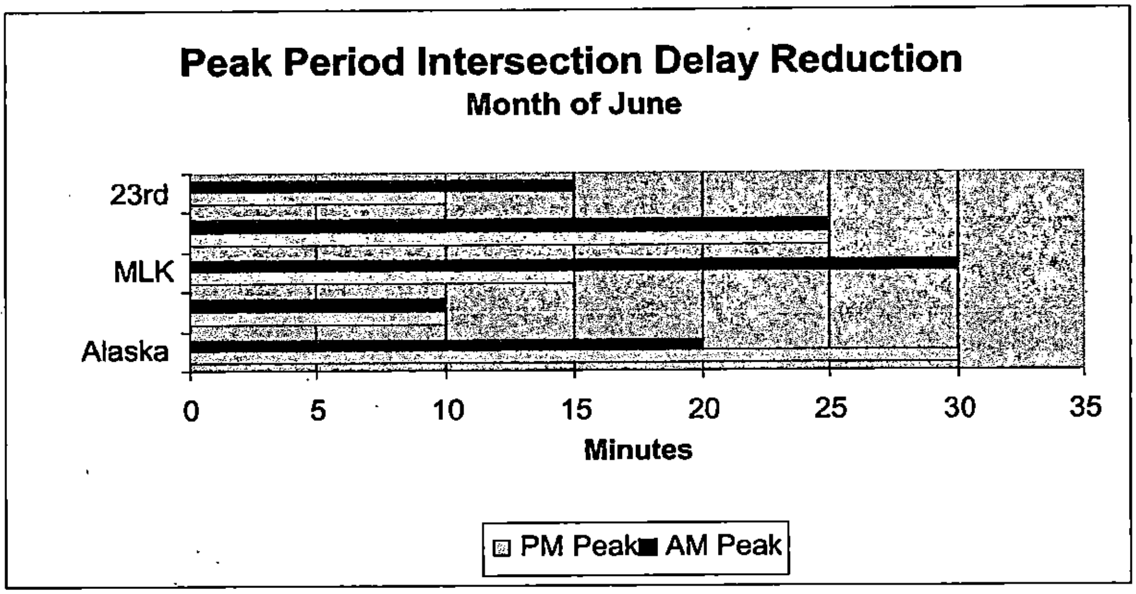


Figure 13:Peak Period Intersection Delay Reduction

Table 11 presents a summary of the data elements, data sources and calculations for the Corridor Summary report. The performance measures discussed above are highlighted.

Table 11: Corridor Summary Report

Data Element	Source	Calculation
Eligible trips (actual)	Corridor Event Log	Count of trips with "eligible" = Y by time period
Trips receiving TSP benefit	Corridor Event Log	Total number of trips with "total delay reduction" > 0
% Eligible trips receiving TSP benefit	Corridor Event Log	Total number of trips where "eligible" is Y and "delay reduction" is >0 divided by total number of trips where "eligible" is Y
Cumulative travel time in corridor for trips receiving TSP benefit (minutes)	Corridor Event Log	Total of "scheduled travel time" for trips where "total delay reduction" > 0 in minutes
Cumulative delay reduction (minutes)	Corridor Event Log	Total of "total delay reduction" for route and time period in minutes
Delay reduction as % of corridor travel time for trips receiving TSP benefit	Calculated	"Cumulative delay reduction" divided by "cumulative travel time in corridor for trips receiving TSP benefit"
Time saved per trip receiving TSP benefit (minutes)	**Calculated**	"Cumulative delay reduction" divided by "trips receiving TSP benefit"
Passengers receiving TSP benefit	Corridor Event Log	Total of average number of "passengers" for each trip with "total delay reduction" > 0
Passenger delay reduction (passenger hours)	Calculated	Total "passengers receiving TSP benefit" times "total delay reduction" converted to hours
Number of late trips	Corridor Event Log	Total number of trips where "schedule status" at the beginning timepoint is > 5 minutes
% Late trips receiving TSP benefit	Corridor Event Log	Total number of trips where "schedule status" at the beginning timepoint is > 5 minutes and "total delay reduction" > 0 divided by total number of trips where "schedule status" at the beginning timepoint is > 5 minutes
% Late trips with TSP benefit that recover to on-time	Corridor Event Log	Total number of trips where "schedule status" at the beginning timepoint is > 5 minutes and "total delay reduction" > 0 and "schedule status" at ending timepoint is < or = 5 minutes divided by total number of trips where "schedule status" at the beginning timepoint is > 5 minutes
Corridor on-time performance for trips receiving TSP benefit	Corridor Event Log	Total number of trips with "schedule status" < or + to 5 minutes at the ending timepoint divided by "trips receiving TSP benefit"
Passenger Stops Avoided	Calculated	Total "passengers receiving TSP benefit" times "total stops avoided"

Figure 14 shows an example of a chart that could be produced from the Corridor Summary Report. It compares travel time savings for routes operating in the Rainier corridor using hypothetical numbers.

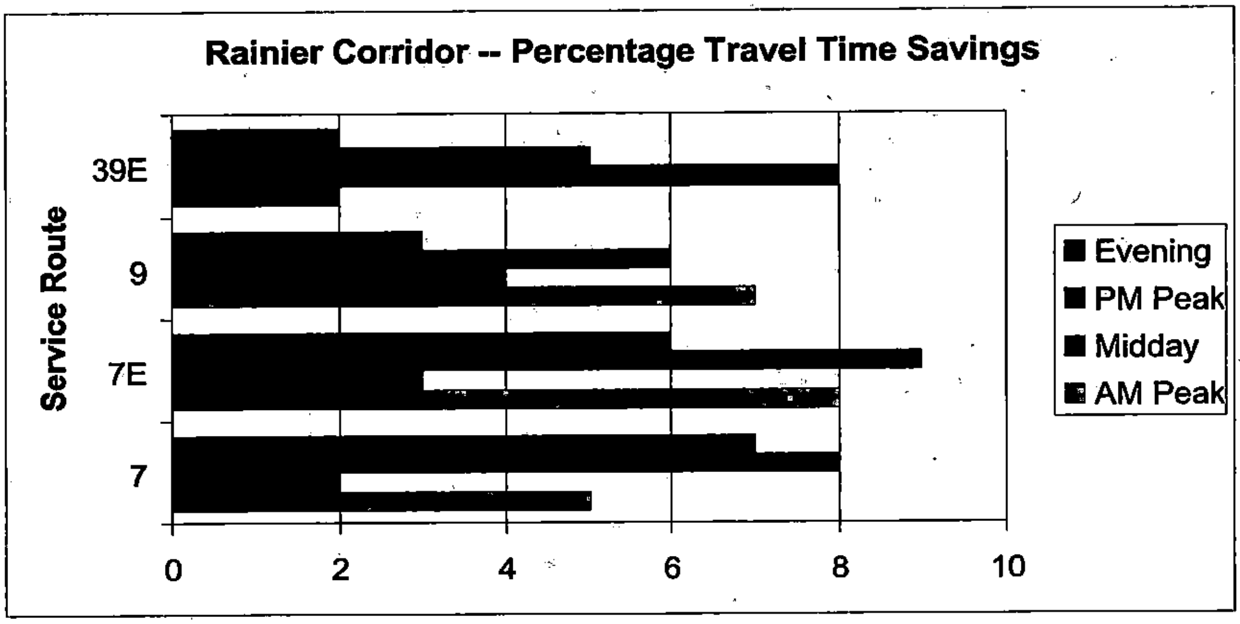


Figure 14: Corridor Travel Time Savings

REPORTS MENU

The TSP operations analyst should have access to a variety of detail and summary reports for ongoing performance monitoring, reporting, analyzing and planning of TSP implementations. The proposed menu tree is shown in Figure 15. It includes detail reports of environment data and TSP events and summary level reporting for TSP intersections and corridors.

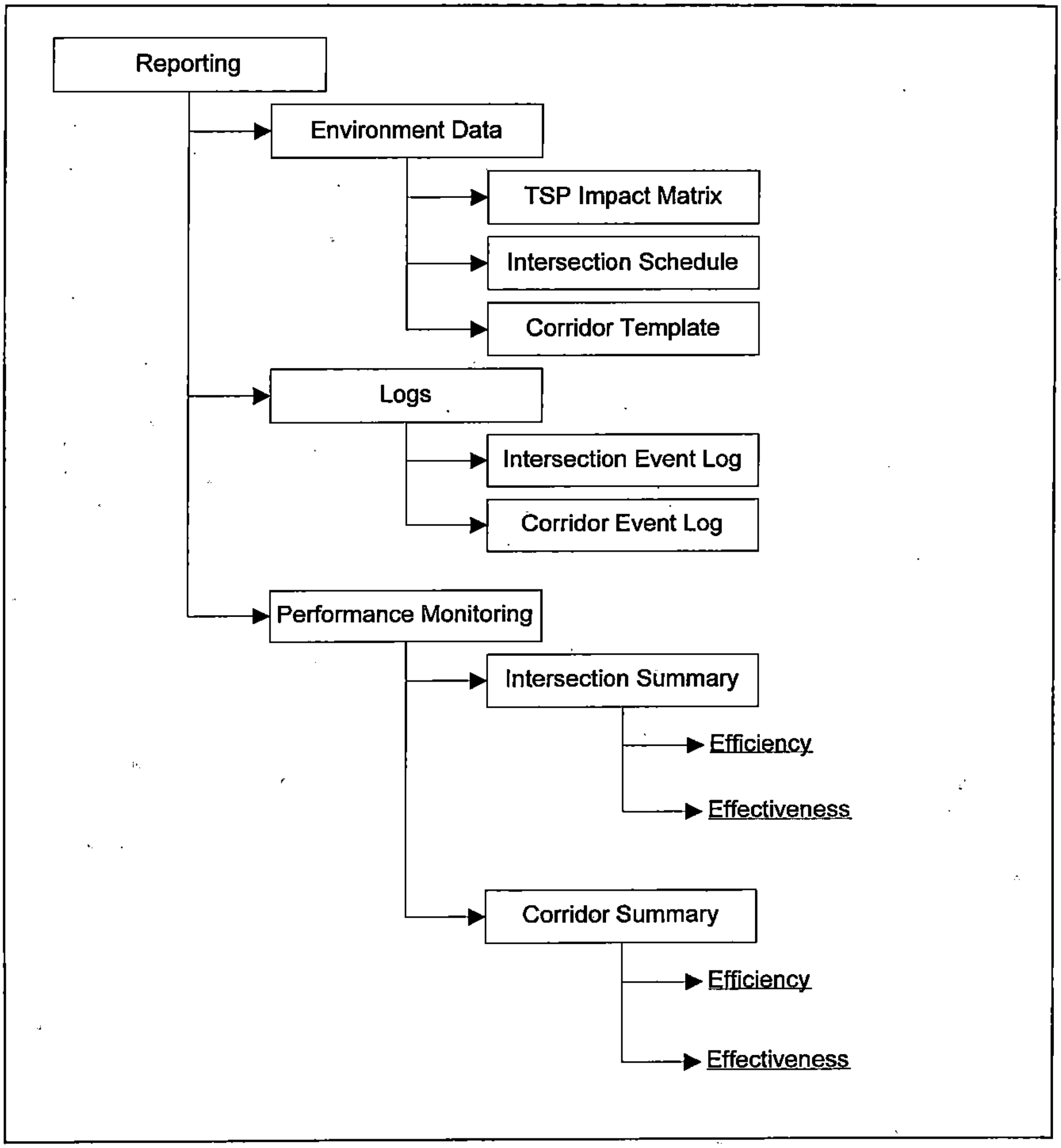


Figure 15: Reports Menu

SECTION 5: PERFORMANCE OPTIMIZATION

The previous section focused on monitoring the performance of the TSP system using measures that reflect specific KC Metro Transit objectives for TSP. Optimizing TSP performance requires taking a closer look at the benefits associated with TSP objectives. This section is intended to provide a framework for thinking about TSP benefits and the operational strategies necessary for achieving and maximizing those benefits.

Optimizing TSP benefits is not a matter of trading off benefits between traffic operations and transit operations. Typical traffic engineering practice is to optimize vehicle flow, generally irrespective of vehicle occupancy. As a result, traffic jurisdictions seek to minimize the impact of TSP actions on traffic flow by setting constraints on the operation of the TSP system (such as a maximum number of calls for priority within a certain time period). This section discusses how these constraints relate to maximizing TSP benefits.

UNDERSTANDING TSP BENEFITS

It is important to understand the nature of TSP benefits in order to determine appropriate operational strategies that will meet the transit agency's goals for TSP implementations. The primary benefits are not mutually exclusive; that is to say that achieving one benefit does not preclude the opportunity to achieve another. The degree to which each benefit can be maximized, though, is constrained by the TSP technology and traffic jurisdiction policy.

Not all TSP benefits are equal in value to the organization. Implemented operational strategies will need to reflect the priority each of the benefits has to the agency.

Express Service and Local Service

A distinction between "express service" and "local service" is essential to understanding TSP benefits. Express service is defined as that part of a route that is operated without an ending scheduled time point constraint. Even though technically there is a scheduled time at the end of an express trip, the bus driver is free to arrive at the end of the route early if conditions allow. Local service, on the other hand, is defined as that part of a route which is constrained by scheduled time points. Bus operators are not allowed to arrive at a time point early. They must maintain a speed that allows them to remain "on schedule" at every timepoint along the route.

Entire routes designated as "express" are not the same as "express service." These routes typically have an initial local segment constrained by time points and an ending section that operates without a time point constraint. For example, the 7 Express northbound operates in local service until South Graham Street and then proceeds to downtown Seattle in express service mode without the need to arrive "on-time" at its ending timepoint.[4]

Customer Service and Operational Efficiency

Another key distinction to be made is between "customer service" benefits of TSP and "operational efficiency" benefits. Customer service benefits are improvements of value directly to passengers. These benefits theoretically ultimately benefit the transit agency as well in terms of attracting and retaining ridership and generating revenue.

Operational efficiency benefits of TSP are those that directly impact the amount of resources required to provide transit service. These operational efficiency benefits are the ones that have the most potential value to the agency because achieving them can reduce the agency's cost. However, operational efficiency benefits from TSP are much more difficult to achieve than customer service benefits.

Four of the seven ITS benefits discussed below are related to customer service and three are related to operational efficiency.

[4] Even if a bus running in express service arrives early at its ending timepoint, it will not be scheduled for its next run until after the time assigned to the ending timepoint.

Facilitating Schedule Changes

Some of the TSP benefits can be achieved by providing TSP treatment to as many vehicles as possible within the limits set by the traffic jurisdiction. However, some of the benefits of TSP cannot be achieved at all without an operating strategy that allows schedules to be changed to reflect reduced travel time and improved reliability.

Three of TSP benefits discussed below require schedule changes in order for the benefit to be achieved.

TSP Benefits

The primary TSP benefits are described below. The first four are customer service related and the last three are related to operational efficiency. Benefits are summarized on Table 12.

Customer Satisfaction Benefits

5. **Improve customer satisfaction with comfort by reducing the number of signal-related stops whenever possible.** Constant stopping and starting at bus stops and traffic signals can be uncomfortable and annoying for bus passengers. Signal-related stops are avoided only if a bus clears an intersection on a green extension. Without TSP treatment the bus would have to stop at a red light and wait for a green light. An early green reduces signal delay but does not reduce signal-related stops. This benefit applies to both express and local service. The fewer the stops for the greatest number of people, the greater the benefit. This is a relatively low value benefit of TSP. (There are some minimal brake maintenance benefits associated with reducing the number of signal-related stops as well.)

6. **Improve customer satisfaction with service reliability by speeding up trips operating behind schedule whenever possible.** Service that is running behind schedule creates anxiety for waiting passengers. It also contributes to a late arrival at a destination and an increased likelihood of missed connections at transfer points. It is a great benefit to customers to minimize the occurrence of late buses or to minimize the degree to which buses are late. This benefit applies only to

local service, since there is no such thing as "behind schedule" for express service. The higher the number of passengers on late buses that receive priority treatment, the greater the benefit.

7. **Improve customer satisfaction with convenience by speeding up express trips whenever possible.** Express service appeals to customers because the travel time is more commensurate with traveling in a car. The shorter the travel time, the more attractive the service. TSP provides the opportunity to minimize travel time in a corridor. This benefit only applies to express service because local service is constrained by schedule requirements. The more express service passengers that receive priority treatment, the better. This benefit has a moderate value to customers because it is intermittent.

8. **Improve customer satisfaction with convenience by reducing <u>scheduled</u> travel time.** Convenience is increased for customers if the scheduled travel time is reduced. This benefit is possible only if the scheduled running time for specific trips can be reduced in anticipation of consistent access to signal priority treatment. This benefit applies to local service only because express service is not constrained by a schedule. For customers, this is a moderately high value benefit because it provides a consistently shorter travel time. (Related operations benefits are discussed below.)

<u>Operational Efficiency Benefits</u>

4. **Reduce service disruptions by speeding up late trips whenever possible.** Operations managers are continually juggling resources to accommodate service disruptions. A mechanical breakdown, for instance, requires that a replacement bus and driver be dispatched to the appropriate location to fill as many scheduled trips as possible. Late buses also create service disruptions that need to be managed by operations staff if they are severe enough. The more late buses that receive priority treatment, the better. This benefit applies only to local service and

has moderately low benefit to operations because it is unlikely that TSP can address severely late service.

5. **Reduce <u>scheduled</u> pay-hours for recovery time and running time by reducing running time variability.** If TSP helps to consistently reduce the variability of running times, it may be possible to reduce scheduled running times and recovery times at the end of the line to reflect increased confidence in travel time estimates. This benefit is possible only if specific trips consistently receive priority treatment. The value of this benefit is high for operations because it can reduce current or future payhours associated with providing the service. This benefit is applicable to both local and express service. The more trips with less variability, the higher the benefit.

6. **Reduce current (or future) vehicle and pay-hour costs by reducing <u>scheduled</u> running times.** If signal delay savings achieved with TSP can be reflected in reduced scheduled running time, it may be possible to reduce the cost of providing the service in terms of payhours and vehicle requirements. More likely is that these efficiencies will allow current resources to accommodate future conditions that otherwise would have required increases in payhours or vehicles to provide the same level of service. The operations value of this benefit is very high because of its potential to save costs. This benefit applies to both local and express service. The more trips with consistent access to priority treatment, the higher the benefit.

OPERATING STRATEGIES

The benefits identified above result from four basic operating strategies. These four strategies are identified below and summarized in Table 12.

Strategy A

Give buses priority whenever possible, unless the bus is ahead of schedule. This strategy moderately improves customer comfort by reducing the number of signal-related stops whenever possible. Some minimal maintenance cost reduction is also possible because of reduced wear on braking systems.

Strategy B

Give priority to express trips whenever possible. This strategy moderately increases customer convenience by reducing travel time for express trips whenever possible.

Strategy C

Give priority to buses that are behind schedule whenever possible. This strategy greatly improves customer satisfaction with service reliability by improving on-time performance. Moderate operational benefits also result from this strategy in the form of fewer service disruptions due to late buses.

Strategy D

Always give priority to specific trips unless ahead of schedule. This strategy enables schedule changes that reflect shorter travel times, and provides the highest customer satisfaction and operational efficiency benefits. Customer satisfaction with convenience is improved with shorter scheduled travel time. Operational benefits include reduced scheduled pay-hours for recovery time and running time because of less running time variability, and reduced current (or future) vehicle and pay-hour costs because of shorter scheduled running times.

Figure 16 shows a comparison of the customer service and operational efficiency values of each strategy.

Table 12: TSP Benefits and Operating Strategies

Operating Strategy		TSP Customer Benefit	TSP Operational Value	Value of Customer Benefit	Value of Operational Benefit
A	Give priority whenever possible unless ahead of schedule	Improve customer satisfaction with comfort by reducing the number of signal-related stops whenever possible.	Reduce maintenance costs related to brake wear.	Moderately low	Low
B	Give priority to express trips whenever possible	Increase customer satisfaction with convenience by reducing travel time for express trips whenever possible.		Moderate	Low
C	Give priority to late trips whenever possible.	Improve customer satisfaction with service reliability by speeding up trips operating behind schedule whenever possible.	Reduce service disruptions by speeding up late trips whenever possible.	High	Moderate
D	Always give priority to specific trips unless ahead of schedule	Improve customer satisfaction with convenience by reducing scheduled travel time. (enable schedule change)	Reduce scheduled pay-hours for recovery time and running time by reducing running time variability.(enable schedule change) Reduce current (or future) vehicle and pay-hour costs by reducing scheduled running times. (enable schedule change)	High	High

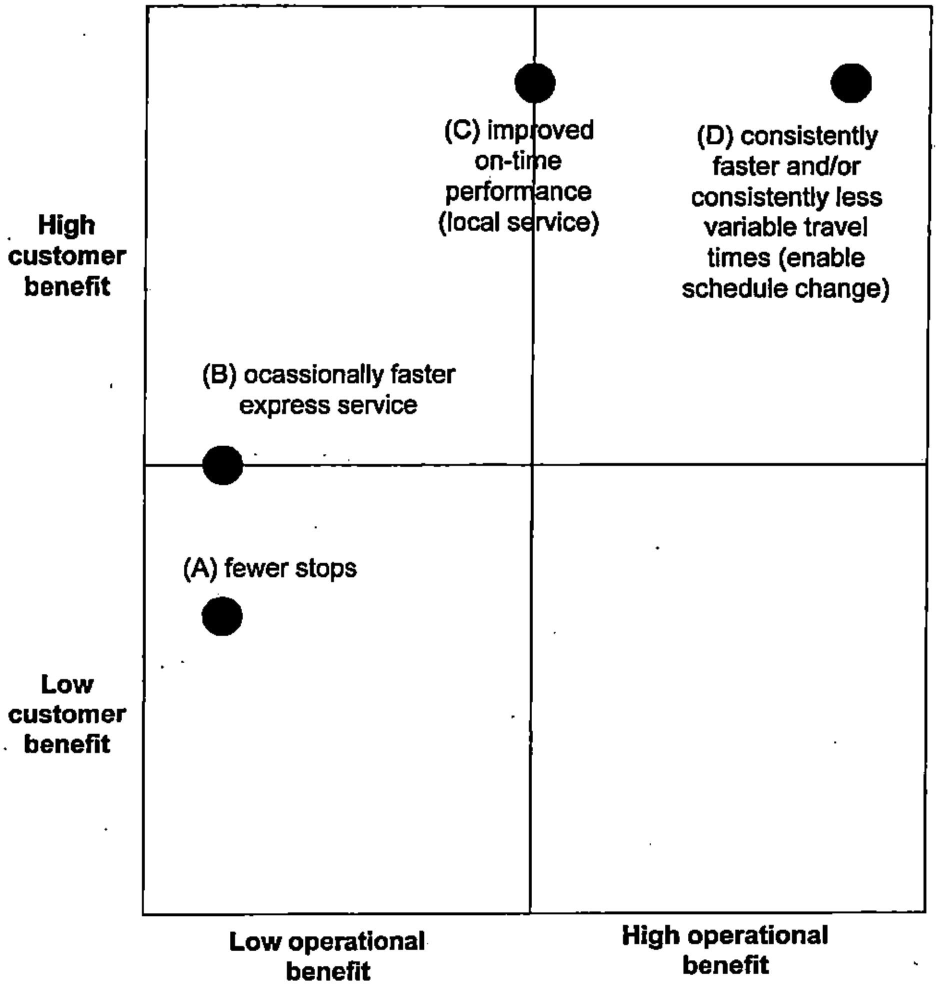


Figure 16: Operating Strategies and TSP Benefits

Specific strategies for maximizing the value of TSP can be prioritized to reflect the relative customer satisfaction and operational efficiency benefits of each strategy. The following are listed in order from most valuable to least valuable uses of transit signal priority.

1. **Request priority**

   if service type = local or express,

   and trip scheduled running time shortened to reflect priority treatment.

2. **Request priority**

   if service type = local,
   and schedule adherence is > X minutes late,
   and passenger load is > Y.

3. **Request priority**

   if service type = local,
   and schedule adherence is > X minutes late,
   and passenger load is < Y.

4. **Request priority**

   if service type = express,
   and passenger load is > Y.

5. **Request priority**

   if service type = express,
   and passenger load is < Y.

6. **Request priority**

   if service type = local,
   and schedule adherence is not early,
   and passenger load is > Y.

7. **Request priority**

   if service type = local,
   and schedule adherence is not early,
   and passenger load is < Y.

ADDRESSING TECHNOLOGY AND POLICY CONSTRAINTS TO MAXIMIZE PERFORMANCE

The ability to effectively implement the higher priority operating strategies is currently constrained either by technology or policy. For example, the initial deployment does not provide a way for the TPR subsystem to know how full or how late a bus is. As a result, eligibility tables must accommodate a desire to give priority to late and full trips by identifying trips that are typically late or full. Optimizing this benefit would require access to "real time" schedule performance and passenger load information, a possibility with the emergence of "smart bus" technology. The analysis above indicates that a priority should be placed on accessing real-time schedule adherence information in order to maximize TSP benefits.

Maximizing TSP benefits requires working within the policy constraints of multiple traffic jurisdictions. These constraints are designed to provide green time advantages to transit, without unduly interfering with the flow of vehicles on the arterial network. The greatest TSP benefits to the transit agency are those that deliver operational efficiency and therefore reduce costs. In order to achieve these benefits at all, the operational strategies must enable schedules to reflect signal delay savings and reduced running time variability. That is, schedule makers can shorten scheduled running times knowing that signal priority treatment will be available to specific trips. The agency may gain far more benefit by identifying a limited number of "eligible" trips so as to guarantee that those trips receive priority than by pursuing strategies that provide more buses with priority but result in a lower value benefit to the agency.

APPENDIX - CALCULATING TSP IMPACT MATRIX VALUES

The purpose of the Impact Matrix is to estimate the TSP benefit for vehicles receiving TSP treatment based solely on information available from the Operations Log. The TSP benefit is expressed in terms of reduced signal-related delay (measured in seconds) and stops avoided (yes or no). The Impact Matrix provides a mechanism to assign benefit to each vehicle for which a priority request to the signal controller is made based the signal phase at the time the priority request is activated and the time between the activation and the time the signal changes to a new phase (including clearance phases).

This appendix provides an example of how the Impact Matrix would be created for one direction, at one intersection for one time period within the day. The key elements of the process are:

1. Determine the signal response for a priority request activated at any point within the signal cycle.
2. Calculate the time between priority request activation and the next signal phase change, for a priority request activated at any point within the signal cycle.
3. Calculate the TSP benefit for a vehicle trip based upon the time the priority request was activated within the signal cycle.
4. Create a matrix relating "activation phase" and "activation to phase change" with the TSP benefit.

The following example is based on an 80-second signal cycle in a coordinated signal system. TSP operations provide for a 15-second extended green phase and early green phase through truncation of other phases. Priority requests are held for 30 seconds. Phase 1 is green in the direction of travel for the bus and phases 2 and 3 are opposing phases for the bus. For purposes of the example, the standard phase lengths, maximum extension and minimum duration times for each phase are given in Table A-1.

Table A-1: Example Signal Timing

Phase[A1]	Standard Duration (sec)	Maximum Duration (sec)	Minimum Duration (sec)
1G	31	46[A2]	31
1C	4	4	4
2G	24	24	11[A3]
2C	3	3	3
3G	15	15	10[A3]
3C	3	3	3

The diagrams shown in Figures A-2 through A-12 illustrate the impact of a priority request at every point in the example cycle. Each diagram uses the symbols presented in Figure A-1. For reference, each diagram includes a depiction of the standard signal timing at the top. On the left, the number of seconds into the cycle is indicated. On the right side of each diagram, information about the activation phase, time to phase change and TSP benefit is listed. All diagrams refer to the example cycle being used to demonstrate the creation of the sample TSP Impact Matrix, shown in Table A-2.

Figure A-1: Legend for TSP Impact Diagrams

[A1] G = green, C = clearance interval

[A2] 46 seconds results from 31 second standard duration of phase plus 15 sec extension

[A3] 10 and 11 second durations are the result of reductions in the non-bus phases allowing an early return to bus phase

Figure A-2 shows that priority requests activated in the first six seconds of the cycle are dropped before the end of Phase 1G. The result is that the standard signal timing is not altered and no TSP benefit is accrued.

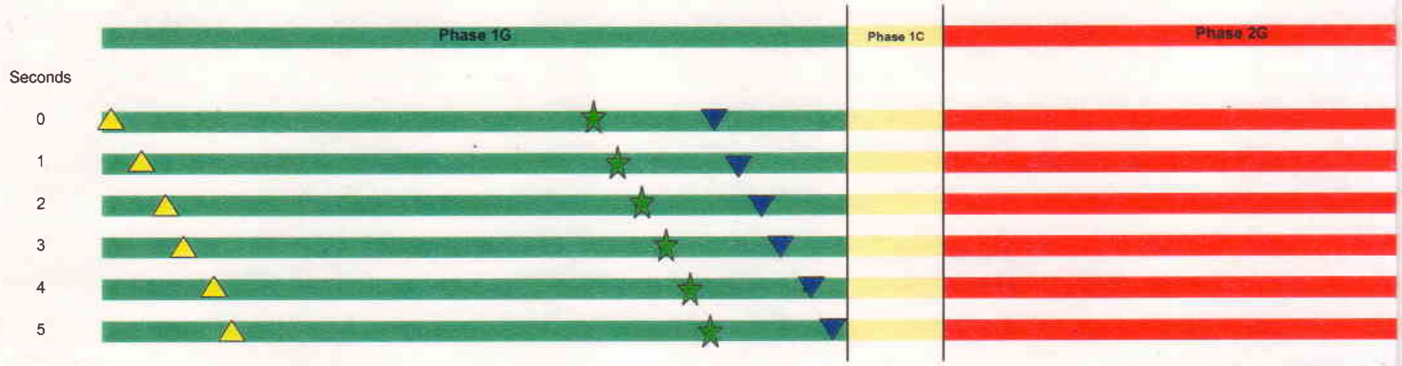


Figure A-2: TSP Im

Figure a-3 shows that priority requests activated in seconds 6 through 10 initiate an extension of Phase 1G up until the time that the request is dropped. The result is that Phase 2G is shortened to accommodate the extended green. In all of these cases however, the bus clears the intersection before the end of Phase 1G and therefore no TSP benefit accrues.

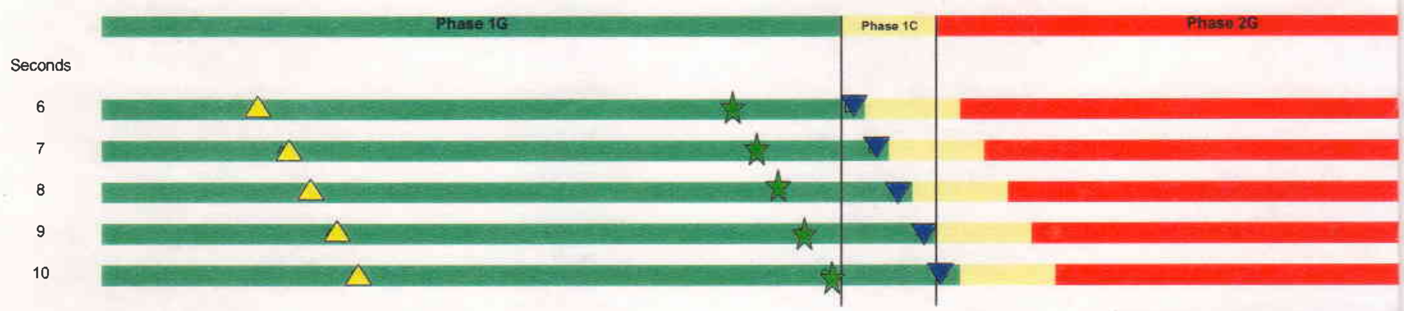
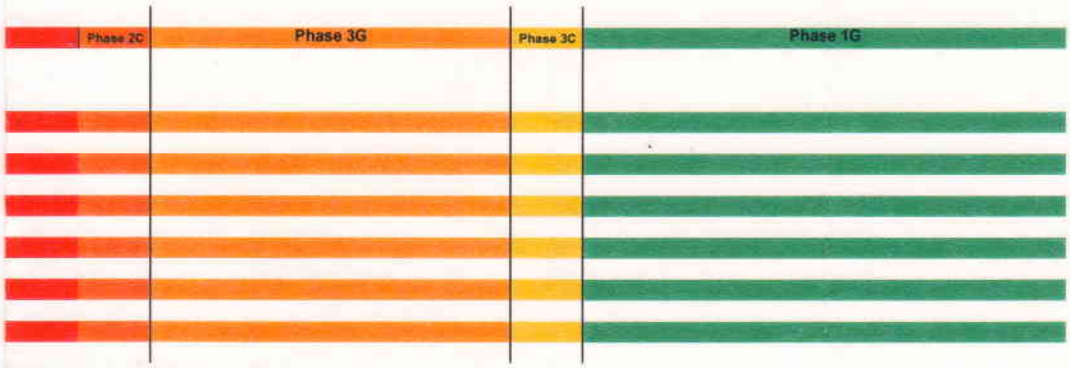
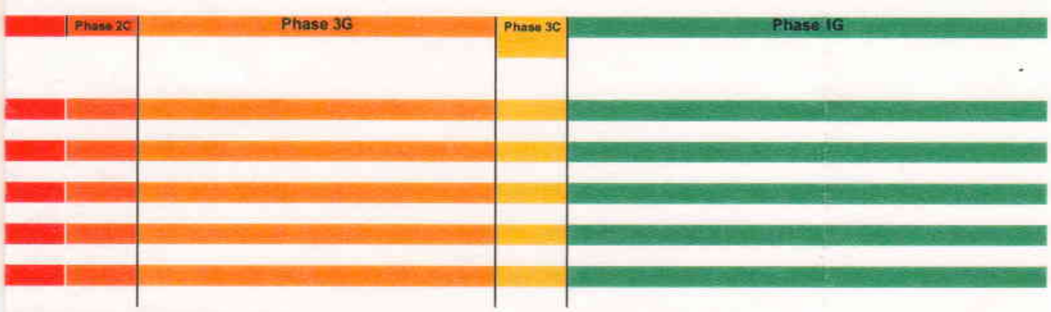


Figure A-3: TSP Imp



Activation Phase	Activation to Change	Benefit
1G	31	0
1G	30	0
1G	29	0
1G	28	0
1G	27	0
1G	26	0

pact (0 to 5 Seconds)



Activation Phase	Activation to Change	Benefit
1G	26	0
1G	26	0
1G	26	0
1G	26	0
1G	26	0

act (6 to 10 Seconds)

Figure A-4 shows the results of priority requests made in the next 10 seconds of the cycle. The request activates the green extension until the request is dropped (still less than the maximum 15-second extension). Both Phase 2G and 3G are shortened to accommodate the extended green. Because the bus enters and clears the intersection after the normal end of Phase 1G, the bus experiences a signal-related delay reduction of 49 seconds. This reflects the fact that without TSP the bus would have had to stop at the intersection. With TSP, the bus is able to clear the intersection without stopping. The bus avoids waiting through the next 4 phases (including clearance phases), a total of 49 seconds.

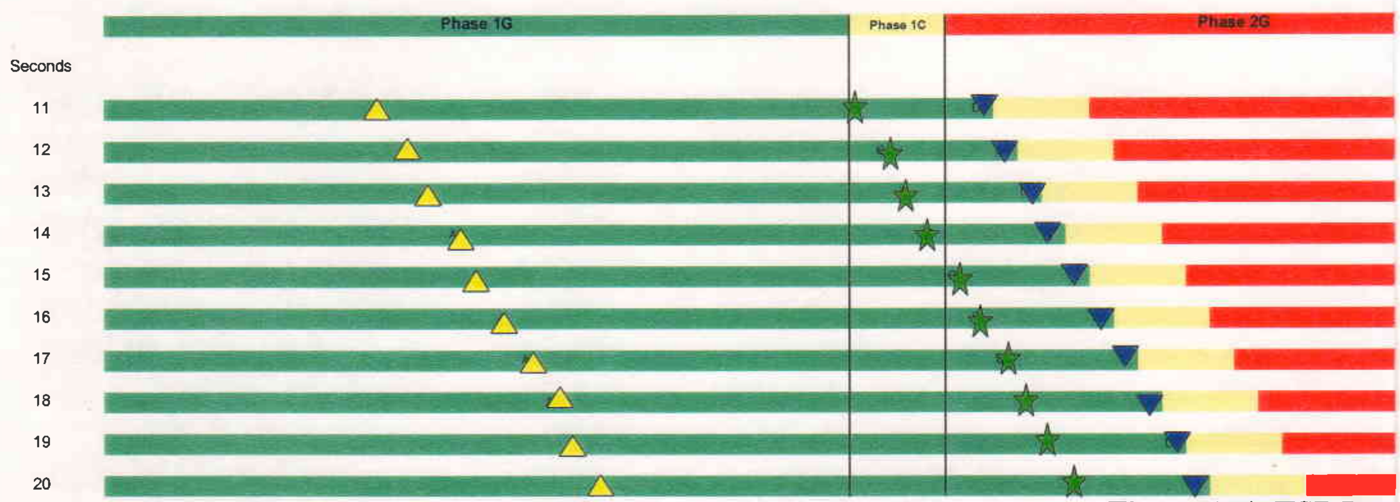
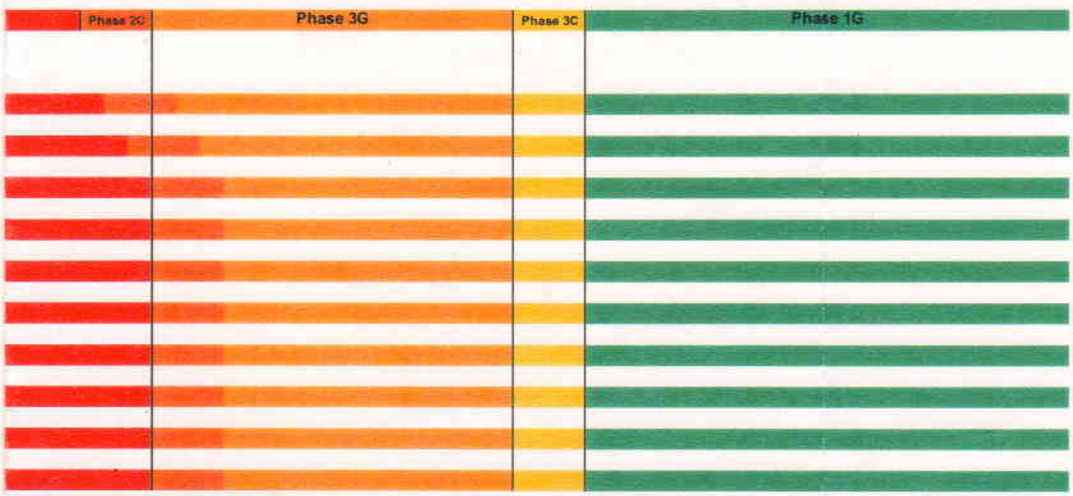


Figure A-4: TSP Imp



Activation Phase	Activation to Change	Benefit
1G	26	49
1G	26	49
1G	26	49
1G	26	49
1G	26	49
1G	26	49
1G	26	49
1G	26	49
1G	26	49
1G	26	49

act (11 to 20 Seconds)

Seconds 21 through 25 are shown in Figure A-5. In these cases the green extension has reached the 15-second maximum and Phase 1G terminates before the TSP request is dropped. The bus enters and clears the intersection during the green extension and accrues the same 49-second advantage described above.

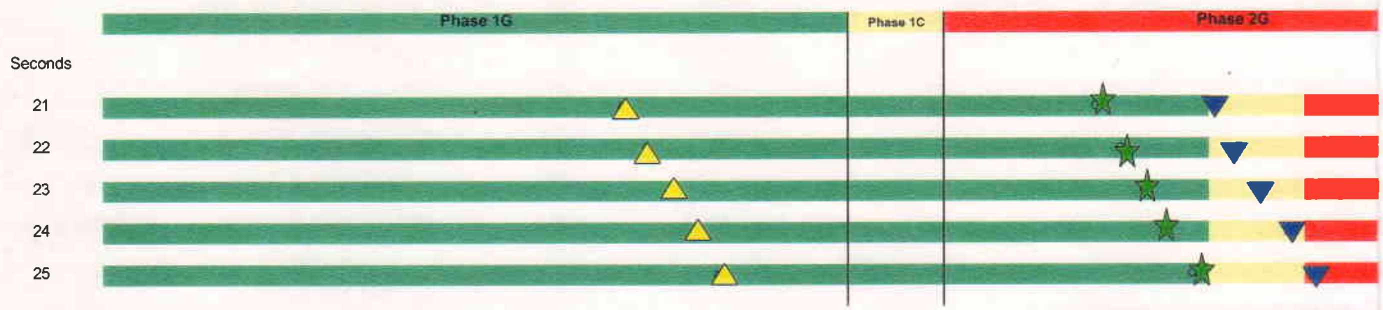


Figure A-5: TSP Imp

When the priority request is activated within the last 5 seconds of Phase 1G, the 15-second green extension is insufficient for the bus to clear the intersection. As a result the bus stops and gains no TSP benefit.

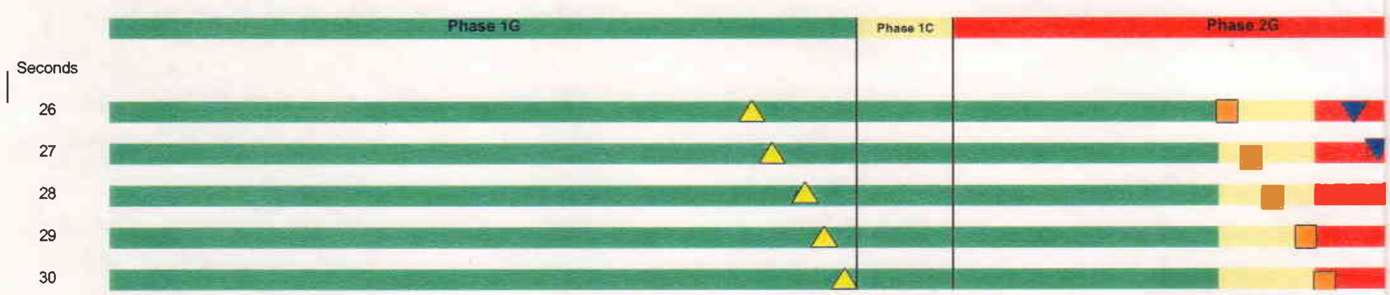


Figure A-6: TSP Imp

Activation Phase	Activation to Change	Benefit
1G	25	49
1G	24	49
1G	23	49
1G	22	49
1G	21	49

act (21 to 25 Seconds)

Activation Phase	Activation to Change	Benefit
1G	20	0
1G	19	0
1G	18	0
1G	17	0
1G	16	0

act (26 to 30 Seconds)

Requests activated after 30 seconds in this example generate an early return to green by shortening both Phase 2G and Phase 3G as shown in Figure A-7. The result is that even though the bus is required to stop at the intersection, the bus will reduce the stop-related delay by 18 seconds, the maximum allowed reduction to Phases 2 and 3.

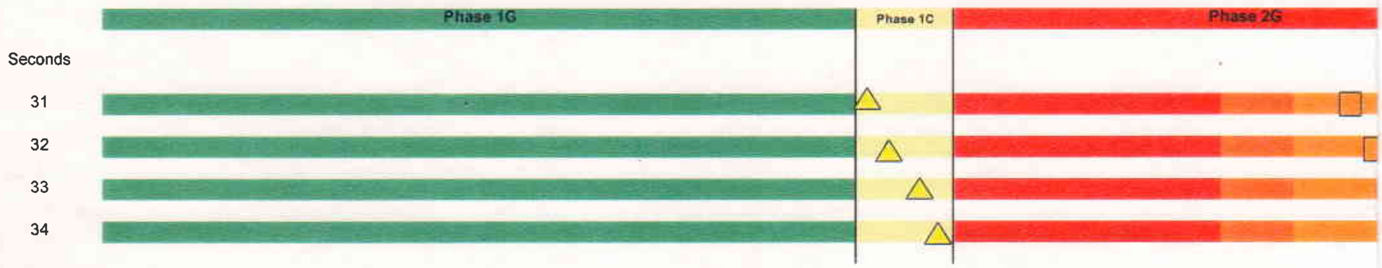


Figure A-7: TSP Imp

During the next 12 seconds, priority requests are activated during Phase 2G as shown in Figure A-8. Because this phase is already underway it cannot be shortened to its minimum. Phase 3 however remains at its minimum duration as in the diagram above. The bus still receives and early green but the benefit decreases for each point within the cycle that the request is activated.

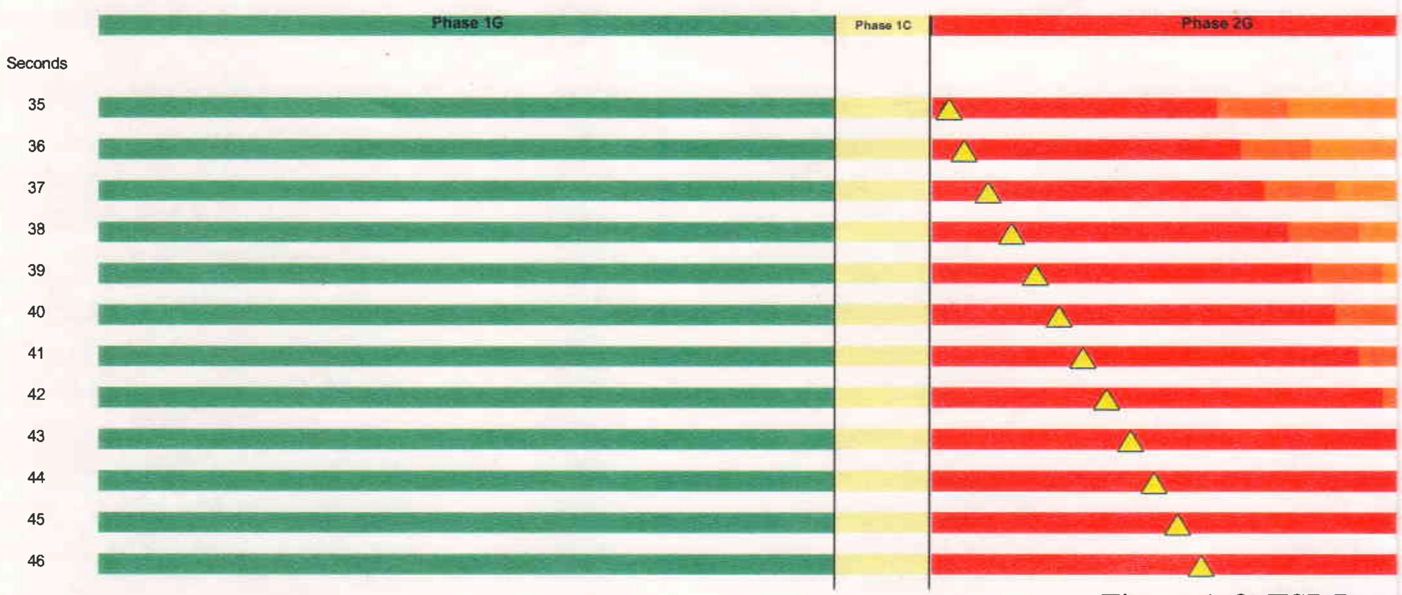
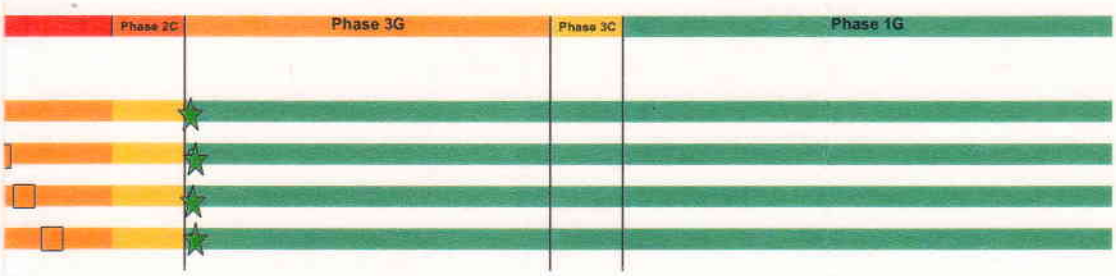
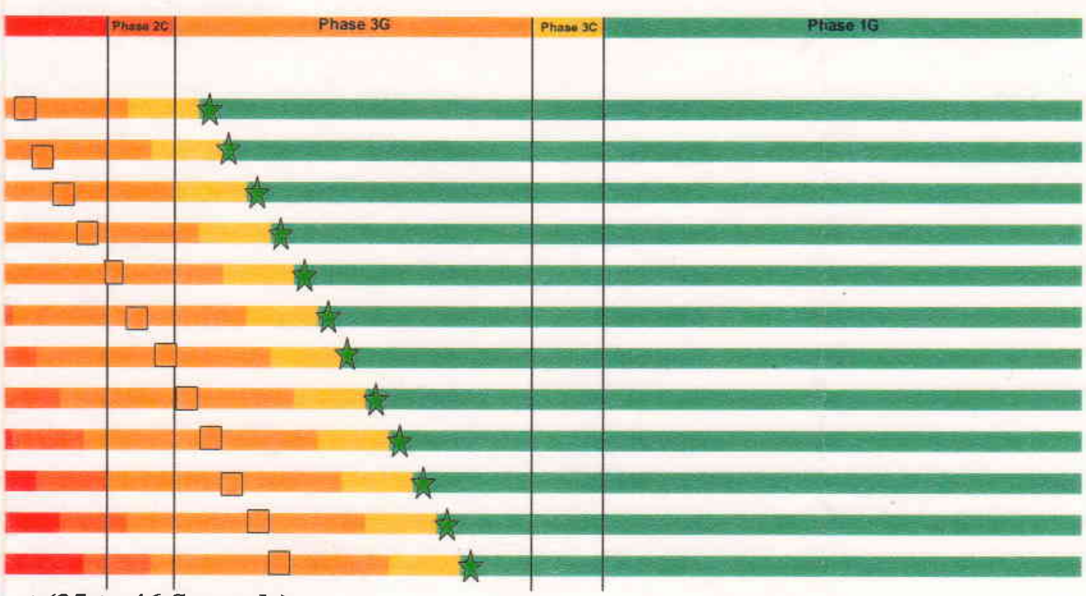


Figure A-8: TSP Imp



Activation Phase	Activation to Change	- Benefit
1C	4	18
1C	3	18
1C	2	18
1C	1	18

act (31 to 34 Seconds)



Activation Phase	Activation to Change	Benefit
2G	12	17
2G	12	16
2G	12	15
2G	12	14
2G	12	13
2G	12	12
2G	12	11
2G	12	10
2G	12	9
2G	12	8
2G	12	7
2G	12	6

act (35 to 46 Seconds)

Figure A-9 shows the result of priority requests activated in seconds 47 through 54. In these cases, requests are activated during Phase 2G beyond the point at which this phase can be shortened. As a result, only Phase 3G is shortened. The bus stops at the intersection but is able to take advantage of a 5 second early return to green.

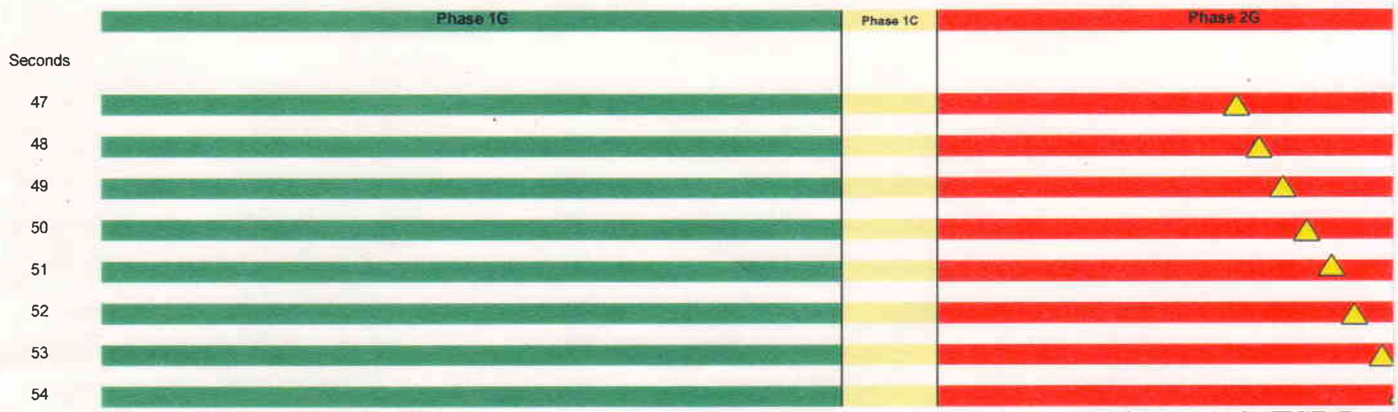


Figure A-9: TSP Imp

Requests activated during seconds 55 through 59 are shown on Figure A-10. These requests are right at the end of Phase 2G and beginning of 2C. They result in Phase 3G being minimized and a 5-second early return to green advantage that allows the bus to clear the intersection without stopping.

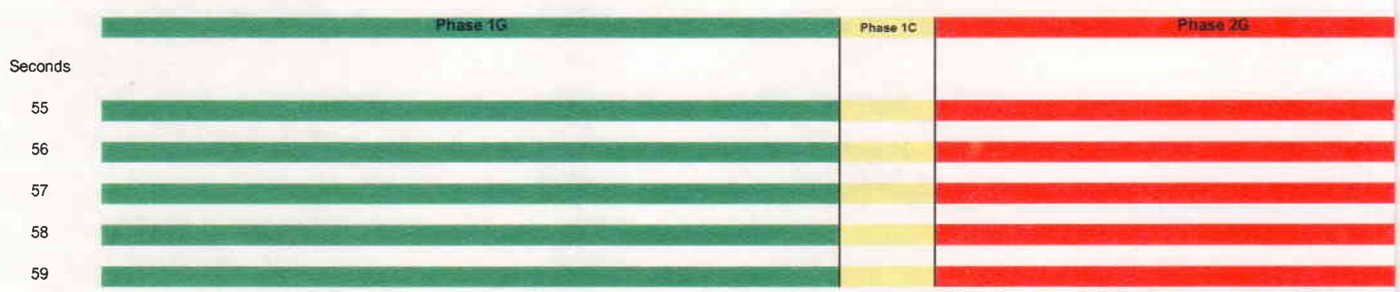
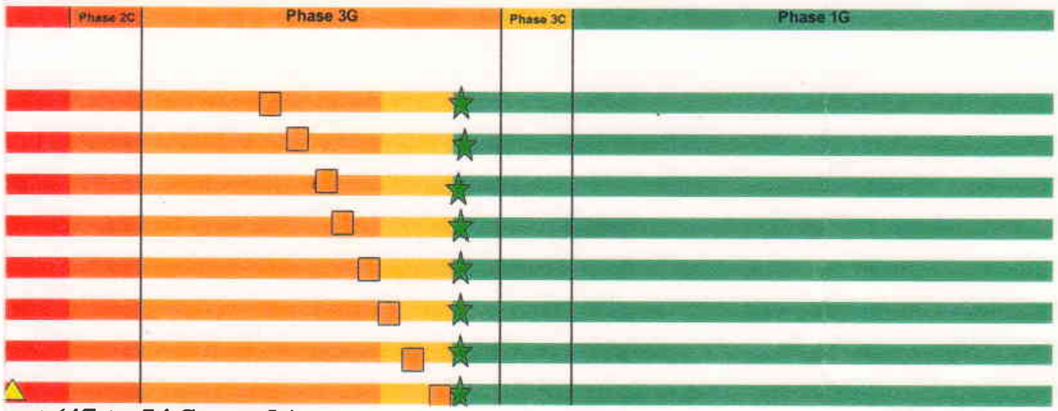


Figure A-10: TSP Imp



Activation Phase	Activation to Change	Benefit
2G	12	5
2G	11	5
2G	10	5
2G	9	5
2G	8	5
2G	7	5
2G	6	5
2G	5	5

act (47 to 54 Seconds)

Activation Phase	Activation to Change	Benefit
2G	4	5
2G	3	4
2G	2	3
2G	1	2
2C	3	1

act (55 to 59 Seconds)

Figure A-10 shows priority requests activated in Phases 2C and 3G that result in a gradual reduction in the amount that Phase 3G can be reduced. The early return to green ranges from five seconds to one second. However, in all of these cases, the bus enters and clears the intersection after the normal return to Phase 1G, therefore, there is no benefit to the bus.

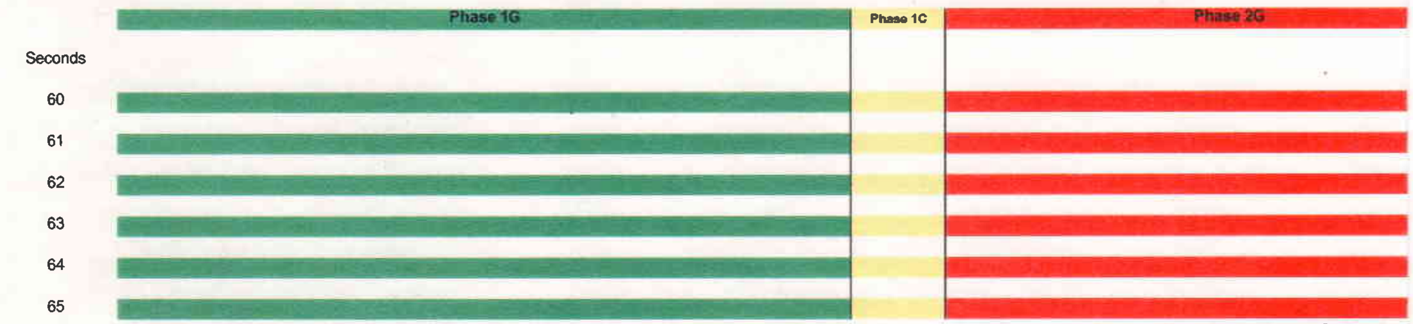


Figure A-11: TSP Im

Figure A-12 shows the final 14 seconds of the cycle. The priority request arrives too late in the cycle to have any effect on the signal timing. The bus clears the intersection without the need for any TSP advantage.

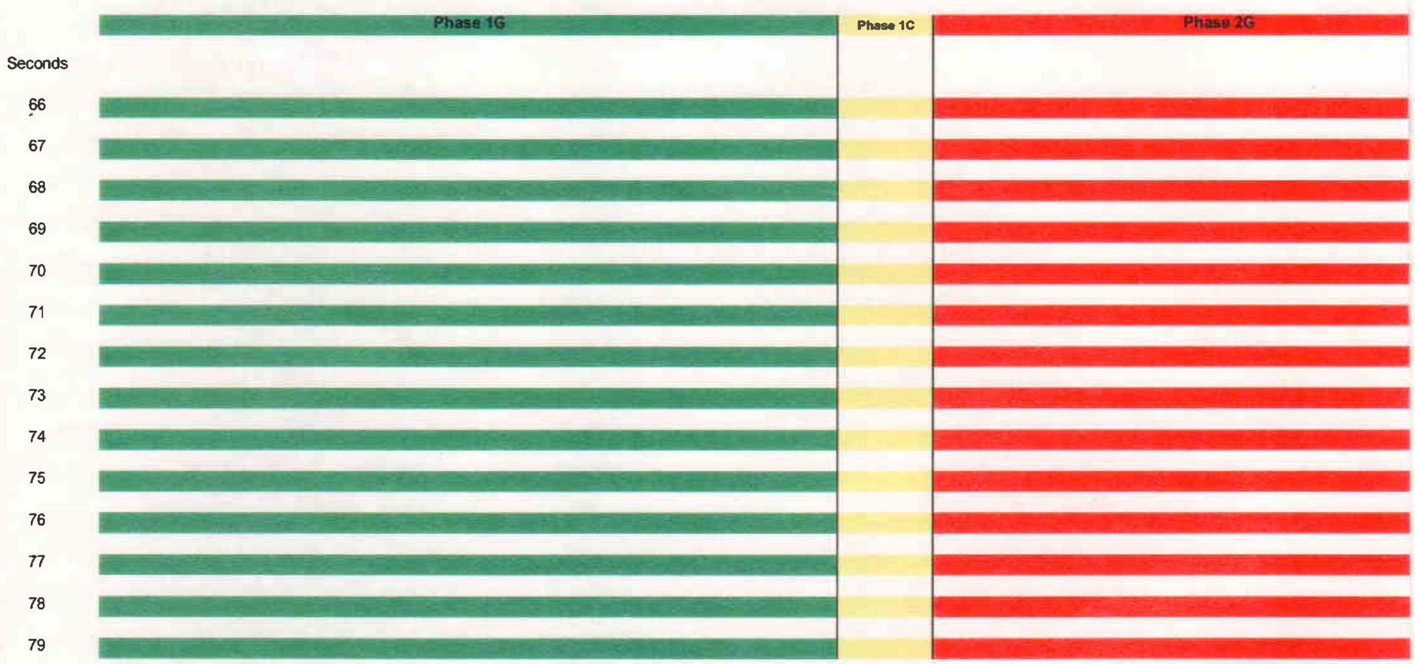
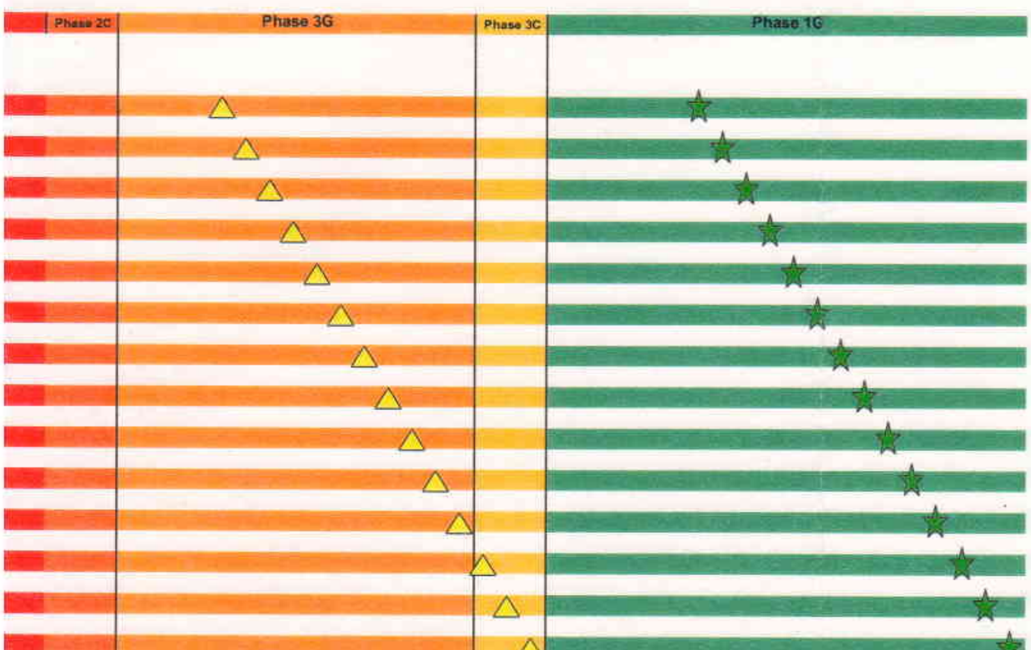


Figure A-12: TSP Im

Activation Phase	Activation to Change	Benefit
2C	2	0
2C	1	0
3G	11	0
3G	11	0
3G	11	0
3G	11	0

pact (60 to 65 Seconds)



Activation Phase	Activation to Change	Benefit
3G	11	0
3G	10	0
3G	9	0
3G	8	0
3G	7	0
3G	6	0
3G	5	0
3G	4	0
3G	3	0
3G	2	0
3G	1	0
3C	3	0
3C	2	0
3C	1	0

pact (66 to 79 Seconds)

Table A-2: Sample TSP Impact Matrix

Time of Day	Activation Phase	Activation to change (sec)	TSP Action	Delay reduction (sec)	Stop Avoided (Y/N)
AM Peak	1G	27-31	None	0	N
AM Peak	1G	26	Extended Green	49	Y
AM Peak	1G	21-25	Extended Green	49	Y
AM Peak	1G	16-20	Extended Green	0	N
AM Peak	1C	1-4	Early Green	18	N
AM Peak	2G	12	Early Green	5-18	N
AM Peak	2G	5-11	Early Green	5	N
AM Peak	2G	1-4	Early Green	2-5	N
AM Peak	2C	3	Early Green	1	N
AM Peak	2C	1-2	Early Green	0	N
AM Peak	3G	1-11	None	0	N