SIGNAL PRIORITY FOR PUBLIC TRANSIT VEHICLES USING ADVANCED TRAFFIC CONTROL SYSTEMS: A COMPARATIVE EVALUATION OF ATSAC, SCATS AND SCOOT

by

Janice Daniel

Professional Mentor
Edwin Rowe
Los Angeles Department of Transportation

CVEN 689
Transportation Information and
Control Systems Design

Department of Civil Engineering
Texas A&M University
College Station, Texas

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SUMMARY

This report provides a comparative evaluation on the operation, experience and logic used in implementing signal priority using advanced traffic control systems. The systems studied included: the Los Angeles Automated Traffic Surveillance And Control (ATSAC) system; the Sydney Coordinated Adaptive Traffic System (SCATS); and the Split Cycle Offset Optimization Technique (SCOOT).

Advanced traffic control systems are traffic-responsive or traffic adaptive control systems which monitor traffic conditions and implement an appropriate signal timing plan that best serves the current traffic needs. These systems provide several advantages over fixed-time traffic control systems in implementing signal priority. The biggest advantage is the ability to monitor traffic conditions on the cross-street and respond to increases in delays on these approaches.

The ATSAC traffic control system presently controls 16 of the intersections crossed by the Los Angeles Light Rail System. Priority for the LRT trains will be provided in the form of partial and full priority. Under partial priority, the green window provided for the LRT-phase will either start earlier than normal, or finish later than normal. The extra length used in the LRT phase will be limited in its length, and no phase with a demand will be skipped. Under full priority the signal operation will be altered to favor the LRT. This may result in the shortening of some phases and the skipping of other phases.

The City of Los Angeles Department of Transportation and the Southern California Rapid Transit District performed a bus priority traffic preemption demonstration project along a ten mile section of Ventura Boulevard in June of 1983. Although this was implemented under a fixed-time control system, the results of the study demonstrate that priority could successfully reduce vehicle delays under traffic conditions and intersection geometry similar to those along the LRT line.

The results of the study showed that on the average priority resulted in savings to bus riders of 3.2 minutes (or 4.2% reduction) for a 77.1-minute round trip bus trip. Bus delays at signalized intersections were reduced by 21.6% from 10.2 minutes to 8 minutes.

The implementation of signal priority under SCATS is facilitated by several features. The first is its ability to monitor the degree of saturation on a cycle-by-cycle basis and to identify critical approaches. A second element is the use of flexible window stretching. This priority treatment provides early starts and phase extensions and makes available the unused priority phase for later phases. The third element of SCATS is its flexibility in the strategic selection of the priority phase. The selection strategies include time of day, tidal flow and intersection congestion.

A priority scheme under SCATS was implemented along two parallel tram routes and three cross routes in a suburb of Melbourne, Australia. The overall results of the study revealed that due to signal priority, there was a reduction in travel time for both trams and cars travelling in the same direction. This reduction was statistically significant for trams

only. Cross street traffic also experienced reduction in travel time with a significant increase in travel time at only one location.

Signal priority under SCOOT is provided through the use of weighting factors which are used to alter the actions of the optimizers to favor traffic on specified links. Under splitweighting, the split optimizer is given a weighting factor where the delay on the weighted links will rise and the delay on the favored links will be reduced. Under offset weighting, the flow on the favored links is increased to enhance its importance in determining the most appropriate offset.

A limited on-street test was conducted using weightings to favor a specified bus route. Benefits measured by the buses were small at all times of the day with a percentage reduction of 3%, 10% and 14% in the AM, Off and PM peak hours respectively.

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INTRODUCTION

The Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) and the Clean Air Act Amendment of 1990 (CAA) will have far reaching effects on the direction of transportation in the United States. The net result will be heavier demands placed on public transit systems to meet mobility and environmental goals. Existing and future transit systems should then be designed and operated to provide an attractive alternative to auto travel. This paper will focus on one measure aimed at improving surface transit movement through the use of signal priority and advanced traffic control systems.

Bus transportation has traditionally served as the backbone of public transportation. Despite the importance and efficiency of buses, compared to the automobile, these vehicles are weighted equally with automobiles at traffic signals where a bus carrying 50 passengers is treated the same as an auto with a single person. Minimizing the delay at signalized intersections could constitute significant reductions in bus travel times.

Light Rail Transit (LRT) is another surface public transit system that competes with the automobile at signalized intersections. LRT systems are becoming increasingly popular in North American cities. The popularity of these systems is due primarily to the operating flexibility of light rail systems as well as the low capital costs associated with at-grade running. As these systems are integrated into the closely spaced intersections of the central business district, it has become important to better control the interaction between auto traffic and light rail vehicles at signalized intersections. To maintain consistent travel times for the LRT and minimize delays, signal priority has been used at at-grade LRT crossings. This, however, may result in peak-hour traffic delays on the cross-street and may interrupt normal intersection operation.

Although it is clear that signal priority can reduce delay to public vehicles at signalized intersections, it is unclear as to the best way to provide this priority without causing considerable delay to cross-street traffic. The use of Advanced Traffic Control systems is proposed as one measure to provide dynamic signal priority. Dynamic signal priority minimizes the delay to both public transit vehicle and to the cross-street traffic.

The traffic adaptive capabilities of advanced traffic control systems make them attractive in a coordinated network because of their ability to monitor traffic conditions and implement signal timing plans that minimize delay not only along the major arterial, but also along cross-streets and throughout the entire network.

This paper provides an evaluation of the use of advanced traffic control systems as a means of minimizing or eliminating the problems associated with signal priority in a coordinated network. The objectives of this paper are to: (1) evaluate the operation of advanced traffic control systems; (2) discuss the ability of these systems to provide signal priority in coordinated networks and central business districts; and (3) to assess the strengths and weaknesses of these systems in accomplishing this goal.

SIGNAL PRIORITY

Signal priority is an attempt to minimize or eliminate delays for transit vehicles at an intersection by temporarily altering the traffic signal phase so that an approaching transit vehicle receives a green phase when it arrives. Although coordination can be used to platoon vehicles through a series of signalized intersections, the variation in travel times of transit vehicles makes this measure ineffective in improving transit operation. The variation in the travel times of public transit vehicles when operating in a surface running mode are due to interaction with other surface running vehicles as well as the uncertainty in passenger loading and unloading times. Figure 1 demonstrates the differing operating characteristics of transit vehicles compared to other surface running vehicles which make it difficult for transit vehicles to travel within existing traffic platoons (1). As a result, public transit vehicles are unable to adhere to time schedules and to effectively compete with automobiles.

An analysis of Toronto streetcar delay showed that 50 percent of all delays were caused by traffic signals. Table 1 describes the breakdown of street delay to these vehicles (2). The table demonstrates that efforts aimed at reducing delay to transit vehicles should concentrate on reducing delay to these vehicles at the traffic signal.

Signal priority, however, is not always beneficial to the overall traffic network, especially in a coordinated network environment. Providing priority for transit vehicles along a corridor with a large number of transit vehicles can cause a coordinated network to be out of step resulting in an overall increase in delay. Providing priority also has the disadvantage of penalizing the cross-street traffic. This can create significant delays at locations where the cross-street carries significant traffic volumes.

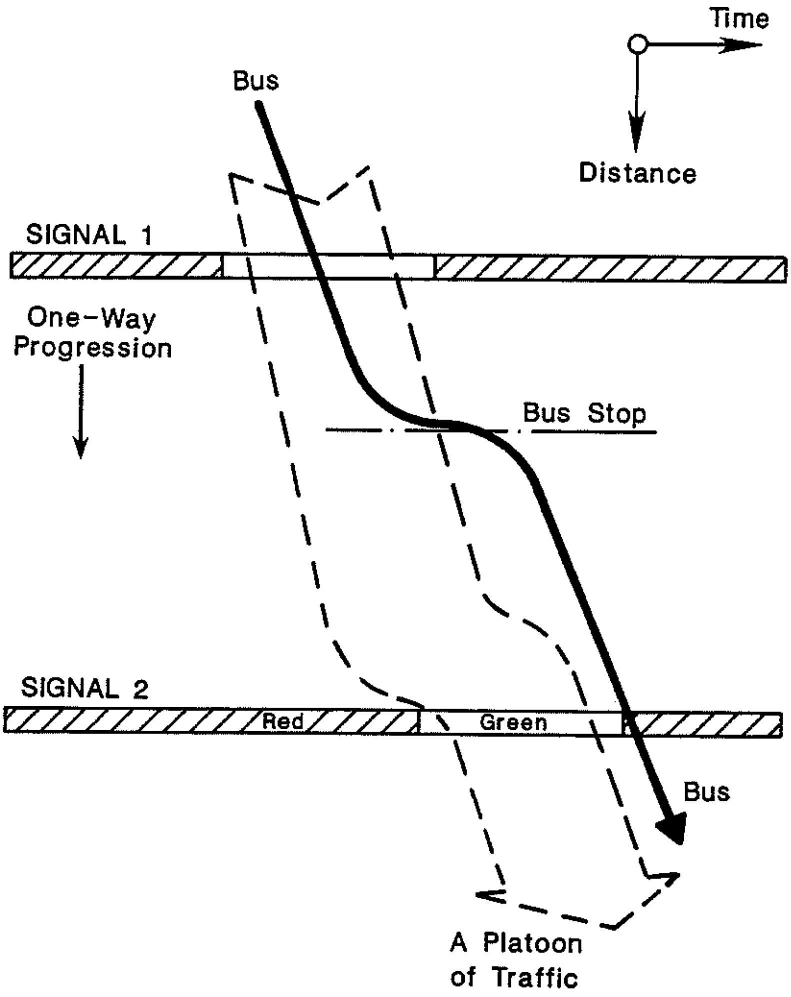

Figure 1. Time-Distance Difference Between Normal Movements of Traffic Platoon and Bus (1).

Table 1. Streetcar Delay (2).

Type of Delay	Percentage of Total Delay
Traffic Signals	49.97
Boarding Delays	42.51
Left or Right Turns	0.98
Accidents	0.32
Traffic Congestion	3.30
Yield and Merge	0.84
Pedestrian Crosswalk	0.67
Parked Automobile	0.10
Traffic Officer	0.12
Construction	0.76
Miscellaneous	0.43

SIGNAL PRIORITY TREATMENT

Signal priority has been implemented in many settings utilizing a variety of techniques. These techniques can be broken down into passive and active priority treatments.

Passive Priority Treatment

Passive priority treatments use a predetermined knowledge of public transit operations to determine which required priority treatment should be implemented. In other words, prior knowledge of the operation of the transit vehicle by time and place determines the signal control to be implemented. These techniques are easily introduced at low additional costs and therefore provide an attractive alternative for improving transit operation. The following outlines several passive priority techniques (3):

(1) Reduced Cycle Time - Reducing the cycle time below that which is required by vehicular traffic reduces the delay and provides greater regularity to the public transit vehicle. This technique requires that the intersection operate below congested levels to avoid increasing queuing delay.

(2) Priority Movement Repetition in the Cycle - By introducing the phase used by the public transit vehicle at more than one point during the cycle, delays to transit vehicles can be reduced.

(3) Green Allocation Weighted Towards the Priority Movement - This technique calls for increasing the green time for movements serving the public transit vehicle. This may introduce delays to the competing movements and may encourage vehicles to use the public transit route.

(4) Phasing Design - The design of the signal phasing should be done to provide preferential treatment to the public transit vehicle. Examples of this include providing a separate left-turn phase or eliminating left-turns, or combining the movements associated with the public transit vehicle with other non-conflicting movements to increase the green time allocated to the public transit vehicle.

(5) Linking of Signals for Tram Progression - Recognizing that public transit vehicles generally travel at lower speeds compared to vehicular traffic, the offsets used in providing progression along an arterial should be designed to accommodate these lower speeds. The choice of speed used in the design, however, should be balanced with minimizing delay to motor vehicles. This could be accomplished by selecting a progression speed that minimizes delay per person rather than per vehicle.

Active Priority Treatment

Active priority improves upon one basic weakness in passive priority treatments, and that is its ability to sense the presence of the public transit vehicle and to select the most suitable priority technique. Active priority has the advantage of being able to: (1) provide sufficient priority to allow the transit vehicle to cross the intersection; (2) avoids providing priority when the transit vehicle is not there; and (3) is sensitive to the non-priority cross-street movements. Using selective detection, stronger priority techniques can be used to directly influence the operation of the signals when the transit vehicle appears. The following discusses several active priority techniques (3):

(1) Phase Extension - This technique extends the green for the public transit vehicle movement while the vehicle is approaching the stop-line or loading and unloading passengers thus allowing the vehicle to clear the intersection.

(2) Phase Early Start - Accelerating the onset of the green phase used by the public transit vehicle when it is determined that the transit vehicle is ready to clear the signal can reduce delays to these vehicles. This technique can also be used to provide an advance green to clear vehicles stored in front of the transit vehicle.

(3) Special Phase - At complex intersections, delays to the public transit vehicle can be reduced by introducing additional phases that favor these vehicles. This special phase may be introduced during those phases that do not accommodate the transit vehicle.

(4) Phase Suppression - Where non-transit movements are accommodated during more than one phase in the cycle, one of these phases can be suppressed to expedite the introduction of the transit phase. The selection of phases to be suppressed should ensure that pedestrians receive ample time to cross the intersection.

(5) Priority Phase Sequences - The phase sequence at an intersection can be adjusted to promote and better accommodate the transit movement. For example, just prior to introducing the transit-only phase, a phase clearing the vehicles stored ahead of the transit vehicle could be introduced. Alternatively, a non-transit phase could be extended to provide a better opportunity to introduce the transit-only phase.

(6) Compensation - To avoid the deterioration of traffic not favored by priority treatment, measures may be needed to compensate the non-transit movements. Included under this technique is phase extension which is a temporary measure introduced for non-transit movements immediately after priority is provided.

(7) Flexible Window Stretching - Flexible Window Stretching is a method of giving active priority in a coordinated system or at an isolated location. This technique builds upon simple or basic window stretching. Under basic window stretching the cycle is separated into a normal main street period ("green window") and a normal cross-street period. As shown in Figure 2, the normal cross-street period is further subdivided into an early start period, an extension priority period and a core phase minima. The core phase represents that portion of the cross-street phase that cannot be used by the priority movement. When a transit vehicle approaches an intersection at the end of the main street period, the vehicle

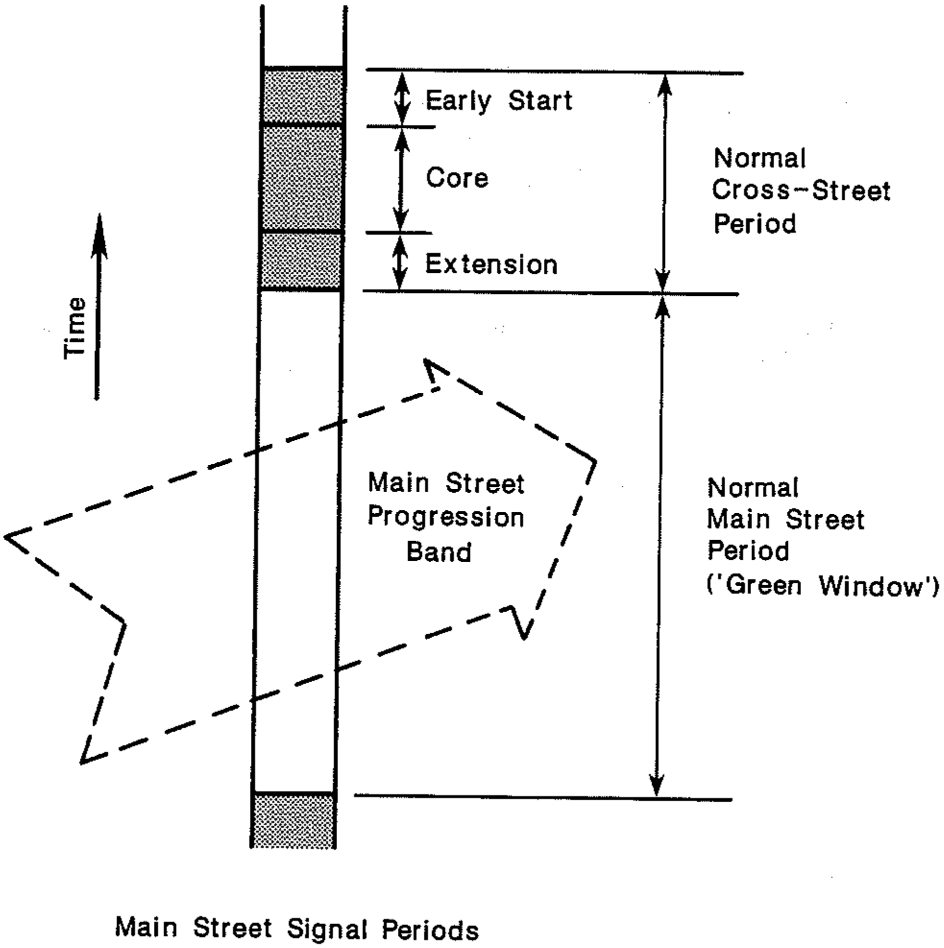

Figure 2. Window Stretching Signal Timing Plan (4).

is detected and the phase is extended. If transit vehicles are detected at a point prior to the green initiation of the main street period, the early phase would be initiated to stretch the green window for these transit vehicles. In the absence of a transit vehicle the cross-street is un-shortened and allowed to run its normal length (4).

The second technique that evolved in the development of window stretching is conditional window stretching. Under this technique, the entire priority time is used for either phase extension, or early start with phase extension favored over early starts. The early start priority treatment is not initiated if the phase extension was previously initiated. This scheme is illustrated in Figure 3. Phase extension is favored over early starts because the success of early starts in reducing delays to transit vehicles varies with the size of the queue ahead of the transit vehicle. Early starts may also be unsuccessful in minimizing delays to the transit vehicle because it places the loading and unloading of the transit vehicle during the main street phase.

The third stage in the evolution of window stretching is a scheme called 'Flexible Window Stretching.' This scheme minimizes delay to the cross-street by utilizing the residual priority that is unused by transit vehicles. This residual priority is then distributed between the early start and extension phases.

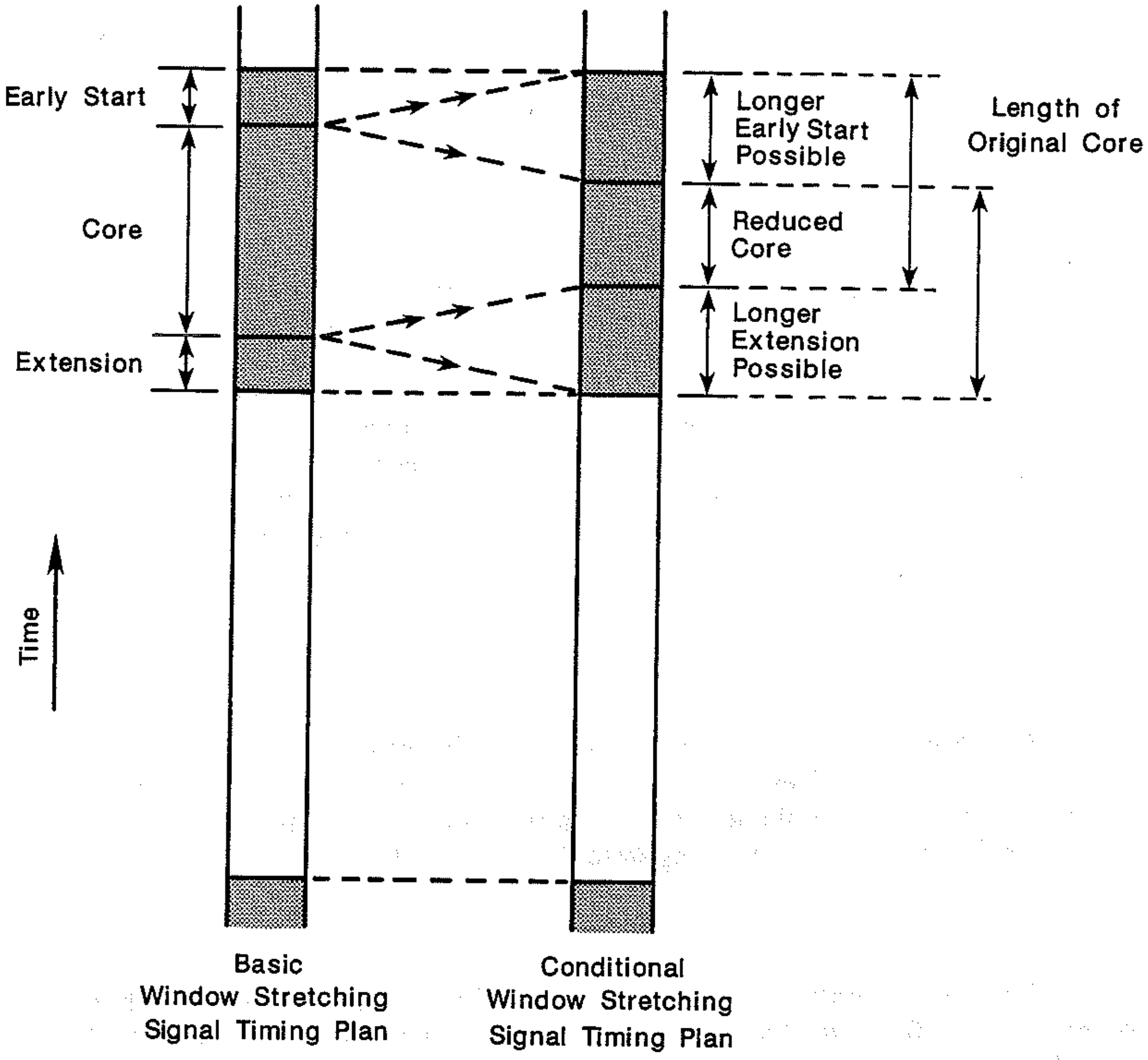

Figure 3. Conditional Window Stretching (4).

TRAFFIC CONTROL SYSTEMS

Although priority treatments exists that can accommodate a coordinated network, large numbers of transit vehicles, and congested locations, the success of these priority treatments is dependent upon the ability of the traffic control system to implement these techniques. Fixed-time traffic control systems are limited in implementing complicated priority treatments. Advanced traffic control systems offer several advantages over fixed-time systems when introducing signal priority. The following provides a discussion of fixed-time systems and four adaptive traffic control systems which have been used to implement signal priority.

Fixed-Time Systems

Fixed-time systems are the most basic type of traffic control system. These systems utilize either simple manual strategies or computer optimization packages to determine green splits, cycle lengths and offsets. Based on historical data, a library of off-line signal plans are developed typically for the AM, Midday, PM and off-peak hours. Coordination of intersections under fixed-time control is achieved by linking local controllers to a master controller. Although these systems can be adapted to respond to recurring traffic conditions, fixed-time systems are unable to accommodate non-recurring traffic conditions caused by accidents, weather conditions or special events. It is the inflexibility of these systems that warrants the development of signal systems that can accommodate not only recurring traffic congestion but also systems that can introduce signal priority (5).

Advanced Traffic Control Systems

Advanced traffic control systems were initially introduced to better manage traffic in a signalized network. These traffic-responsive or traffic-adaptive control systems monitor traffic conditions and implement an appropriate signal timing plan that will best serve the current traffic needs. The following describes four of these traffic-responsive techniques.

Urban Traffic Control Systems (UTCS)

The first-generation Urban Traffic Control System (UTCS) used off-line plans based on historical traffic data. The appropriate plan was manually selected by time-of-day or the cycle lengths; phase splits and offsets were developed off-line, and the appropriate prestored timing plan was automatically selected based on detector data. Tests performed in Washington, D.C. and in New Orleans showed improvements over previous control systems. However, little improvements occurred between time-of-day selection and automated selection of timing plans (5).

The second-generation UTCS strategy utilizes a real-time, on-line system that computes and implements signal timing plans based on real-time surveillance data and predicted changes. This strategy was unsuccessful in improving traffic conditions with an increase in delay from 1.1 percent to 9.3 percent when compared to fixed-time plans. The failure of the system was attributed to: (1)significant transition delay between the time the plan is implemented and the benefits achieved; (2)predicting traffic conditions based on random variations in traffic flow led to inaccurate predictions; (3) delay in predicting traffic conditions during an unexpected event; and (4) poor signal plan selection as a result of unexpected events and faulty detector data.

The third-generation UTCS strategy attempts to provide a fully responsive, on-line traffic control system. The system utilizes two optimization strategies. The first strategy, to be used under saturation conditions, provides signal coordination by utilizing a simulation that adjusts signal timing to minimize a weighted sum of delays and stops. The aim of the second strategy is to maximize throughput and minimize queue lengths to avoid the blocking of adjacent intersections. Overall, this UTCS strategy was unsuccessful in reducing delay with an evaluation in Washington, D.C., showing an increase in delay ranging from 3.4 percent to 15.2 percent over the time-of-day signal timing selection plan.

Automated Traffic Surveillance And Control (ATSAC)

The Los Angeles Automated Traffic Surveillance And Control (ATSAC) system utilizes FHWA's UTCS enhanced package to provide a flexible traffic management tool. The first phase of the ATSAC system was installed in June 1984 and included 118 intersections and 396 detectors. The success of the system led to the expansion of the intersections under ATSAC control to 800 by mid-1992 and 1200 by early 1993. By 1998 a total of 4000 signalized intersections are scheduled to be within the ATSAC system.

The hierarchy of the system is illustrated in Figure 4. Each ATSAC area is controlled by a separate minicomputer which can handle up to 400 intersections and 1600 detectors. Loop detectors located on the approaches to intersections of arterial streets provide traffic data to the Control Center in the form of volume counts and occupancy data. Type 170 traffic controllers, which are used throughout the network, serve as an interface between local and centralized control. Closed circuit television is used by control center personnel to supplement the electronic data gathered from loop detectors.

The ATSAC system can accommodate 64 separate timing plans with 11 presently stored in the computer. The system utilizes four traffic control strategies to determine the appropriate signal timing plan. The first strategy utilizes the TRANSYT-7F model to generate a series of three to nine time-of-day plans. These plans are based on manual traffic counts and include plans for special events and other unusual occurrences. After the plans are implemented they are fine-tuned based on observation of traffic conditions. A second strategy used in determining the most appropriate signal timing plan is the use of critical intersection control. This strategy utilizes a real-time algorithm based on existing traffic demand to determine the green split at intersections. The third strategy is a traffic responsive control which utilizes a computer algorithm that matches surveillance data with the data used to create the available timing plans to select the timing plan. The fourth strategy attempts at providing temporary manual override of the automated timing plans under circumstances when nonrecurring traffic conditions exists.

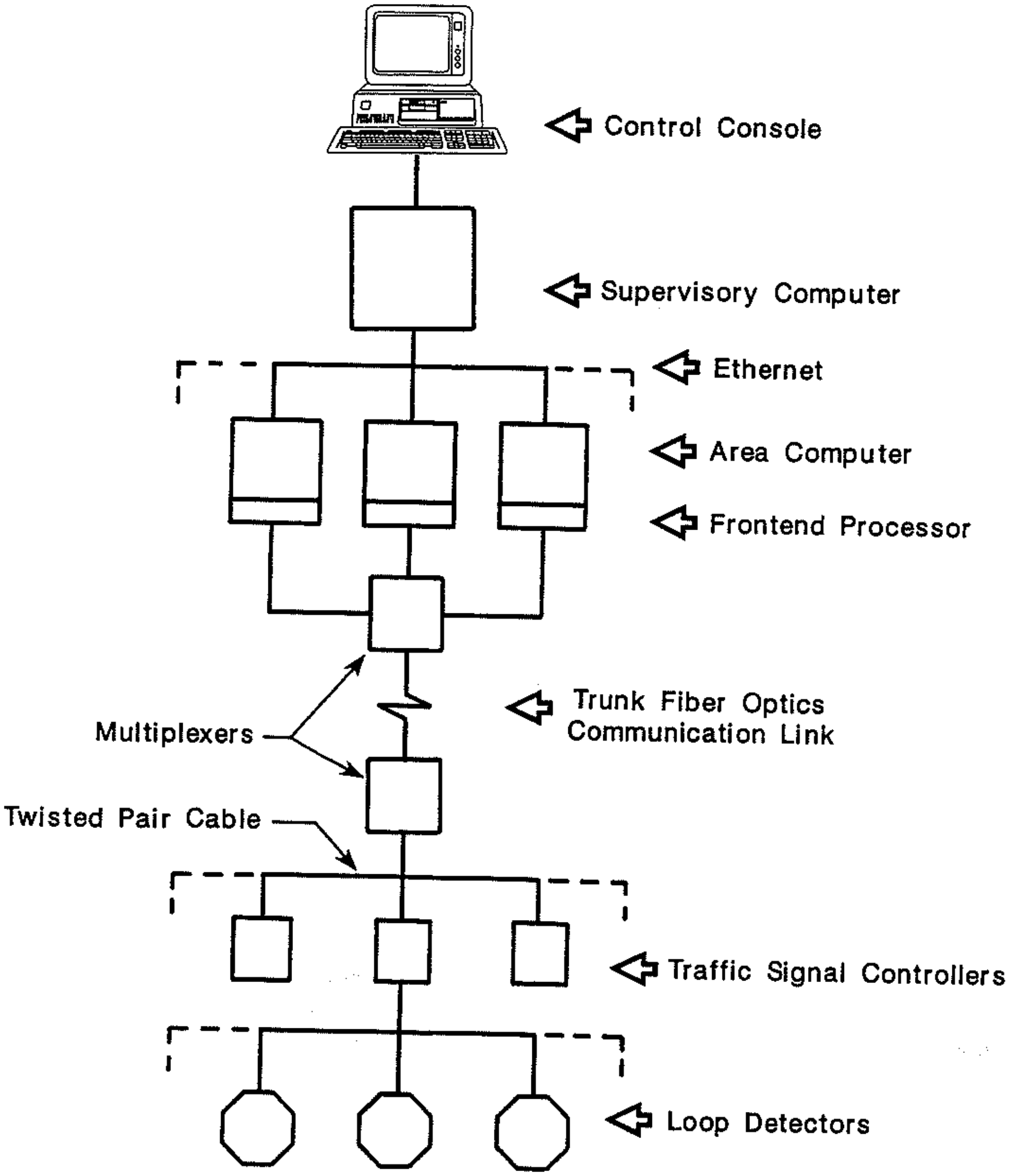

Figure 4. The ATSAC Hierarchical System (6).

The implementation of 1.5 generation software has resulted in an automated development of traffic signal timing plans. Utilizing the 1.5 generation, a new signal timing plan is considered when a change in traffic flow is considered significant. If this occurs, new timing plans using TRANSYT-7F and traffic volumes obtained from loop detectors are developed and stored (6).

Cycle Length. Under time-of-day control, the cycle length is determined from TRANSYT-7F based on manual traffic counts. When optimizing cycle lengths, TRANSYT-7F minimizes the Performance Index (PI) which is a linear combination of delay, stops and queues. Under critical intersection control and traffic responsive control, cycle lengths are unchanged from the overall network plan. Manual override control does not operate within a cycle length but overrides the existing timing plan to accommodate observed traffic conditions.

Phase Split. Under time-of-day control, the phase splits are determined through TRANSYT-7F. TRANSYT-7F uses a "hill-climbing" optimization process to select the phase length that minimizes the PI. Under critical intersection control, the green split is adjusted on a cycle by cycle basis and reflects traffic demand. Under traffic responsive control the timing plan that best accommodates the current traffic plan is selected from a predetermined library of timing plans. Manual override control responds to special events, severe congestion, or other unusual situations detected from the monitor screens. As a result the phase splits are manually selected and based on observed traffic patterns, and temporarily override the existing timing plan.

Offsets. Offsets are determined similarly to the phase splits with the exception of critical intersection control which maintains the offset of the overall network plan.

Sydney Coordinated Adaptive Traffic System (SCATS)

The Sydney Coordinated Adaptive Traffic System (SCATS) combines several features of UTCS-1 and UTCS-2. Signal plans are selected based upon traffic conditions and adjusted based on traffic conditions at critical intersections. These critical intersections control coordination within subsystems, and subsystems coordinate with other subsystems as traffic demands vary (7).

The hierarchy used in SCATS begins at the regional level with a regional computer that maintains autonomous responsive control of up to 120 local controllers. This computer operates independently to the central computer except for centralized monitoring of system performance and equipment status. The controllers in the region are broken down into systems which in turn are made up of sub-systems. Sub-systems can include from one to ten signalized intersections. Interaction does not occur on the system level; however, it does occur on the sub-system level.

The degree of saturation(DS) is the most important traffic parameter used by SCATS. The DS is defined as the ratio of the effectively utilized green time to the total available green time. The effectively utilized green time is defined as the amount of time it takes for vehicles to cross the stop line. This time includes not only the time for the physical vehicle to cross, but also the space surrounding the vehicle. Using inductive loop vehicle detectors, traffic flow data including the number of vehicles counted during green on the approach, the total time that the loop is unoccupied during the green, vehicle actuation data is collected from all approaches at every intersection and passed on to the regional computer. This data is then used, on a cycle by cycle basis, to determine the phase split plan, internal offset plan, external offset plan and cycle length for the sub-system.

Cycle Length. SCATS first determines the cycle time required for each sub-area using Webster's method. During off-peak periods, SCATS selects the minimum of two or three precalculated cycle times, giving good two-way time-distance progression. This common cycle time is updated with each cycle, using incremental steps of between one and six seconds based on the degree of saturation of the sub-area. The merging or 'marrying' of two sub-areas or the divorce of these sub-areas is determined using simple empirical rules based on traffic flows and intersection spacings. Coordination of a network within SCATS is provided by coordinating sub-areas. When marrying two sub-areas, the common cycle time for the combined area is the larger cycle time of the two separate sub-areas (8).

Phase Split. A set of four predetermined phase split plans, including intergreens, is available within each sub-area. These plans are selected based on an algorithm that equalizes degrees of saturation at critical intersections. Also available is a set of vehicle actuated intersection control tactics to be implemented with each plan. These tactics include phase skipping, transfer of spare time, gapping and defining phases that will benefit from spare time or additional time gained by cycle time increase. These tactics are implemented during various time periods of the day and therefore make SCAT flexible in handling fluctuating traffic flows as well as adaptable to providing signal priority.

Offset. SCATS utilizes five internal and five external offset plans. The internal offset refers to offsets between intersections within a subarea, and the external offset refers to the offset between two subareas. The selection of the appropriate offset plan is based on current cycle time, phase plans, or the directional splits of traffic flow. During the peak hour the offsets are determined for the heavier direction of travel to ensure that the most significant traffic movements receive progression. The internal offset is based on the current cycle time and a progressive speed factor; the external offset is selected by an algorithm which maximizes the bandwidth or platoon progression.

Split Cycle Offset Optimization Technique (SCOOT)

Split Cycle Offset Optimization Technique (SCOOT) was developed jointly by the Transport and Road Research Laboratory and a consortium of U.K. companies from the private sector. Developed as a coordinated, fully responsive traffic control strategy, SCOOT reacts automatically to changes in traffic flow, adjusting the cycle time, the splits, and the offsets in accordance with an on-line TRANSYT-type optimization process (9).

Vehicle detectors collect traffic flow data on the approaches to all signalized intersection under SCOOT control. Figure 5 shows the hierarchical structure of the flow of information in SCOOT. This data is collected, processed and stored in the form of link cyclic flow profiles (CFP). A CFP is a measure of the average one-way flow of vehicles passing a point upstream of a signal during a cycle. SCOOT continually updates the CFP;

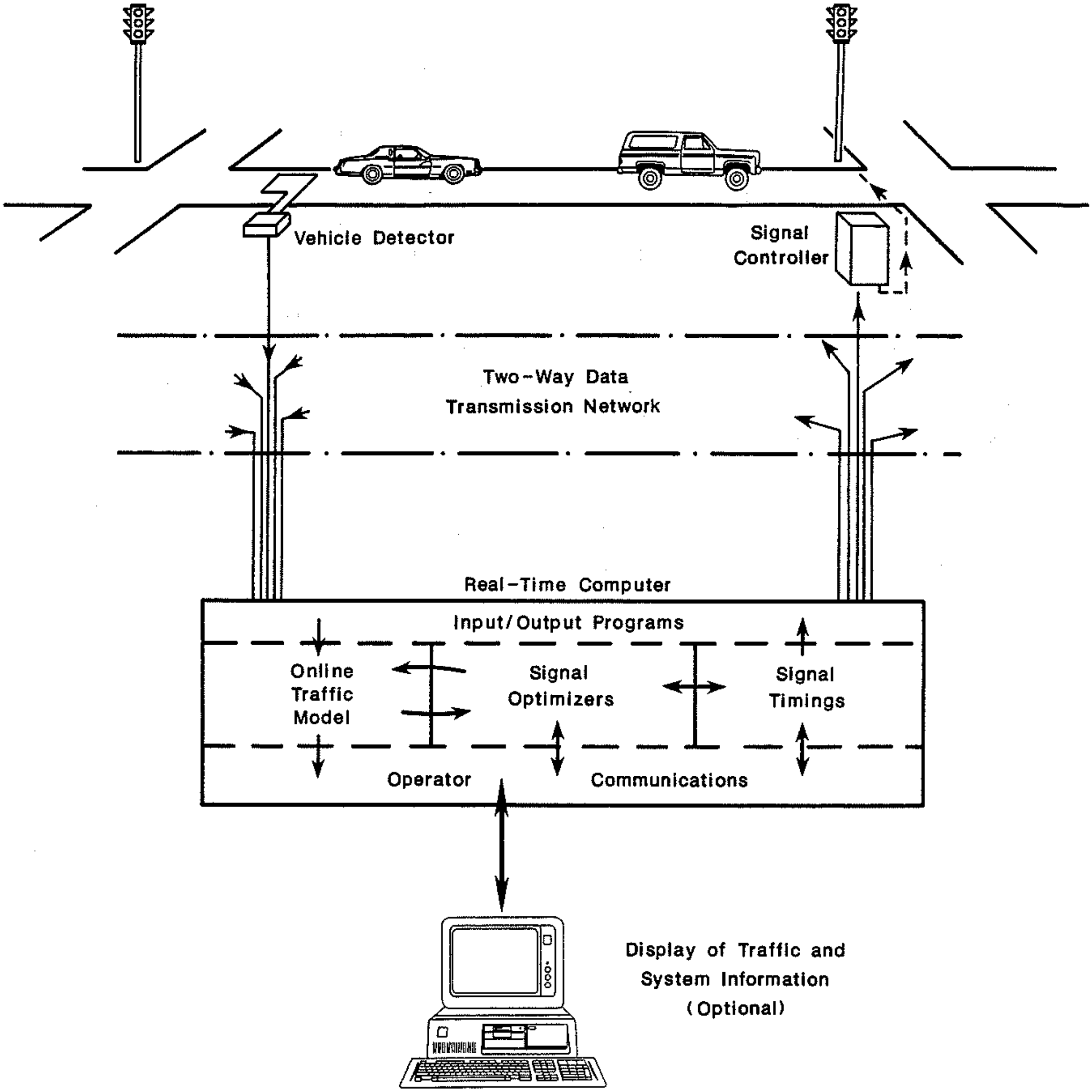

Figure 5. The Flow of Information in a SCOOT Urban Traffic Control System (9).

and using preset saturation flows and link journey times, the queue size, discharge time of the queue and the effects of alterations in the offsets and splits can be predicted. Figure 6 shows how data from the cyclic flow profiles is translated into queue lengths.

Cycle Length. To maintain coordination in a network, SCOOT uses a common cycle length. The cycle time optimizer varies the cycle length to assure that the maximum degree of saturation at any approach is less than 90%. The decision to change cycle length occurs when it is determined that there will be a net savings from single or double cycle operation of the new cycle length. Double cycling is the operation of an intersection at one-half of the common cycle time. The cycle length of a sub-area can be varied in increments of a few seconds at intervals of not less than 2.5 minutes. Each sub-area can vary its cycle length independent to other sub-areas within predetermined bounds.

Phase Split. Based on predicted queue lengths and the estimated degree of saturation, phase splits are optimized in small steps of a few seconds. As traffic conditions warrant, predetermined signal plans are adjusted to produce the best results. The split optimizer implements the alternative that minimizes the maximum degree of saturation on the approaches to the intersection.

Offset. The offset optimizer estimates from the cyclic flow profile whether an alteration to the offset will improve progression. The optimizing algorithm minimizes a performance index using delay, stops and congestion.

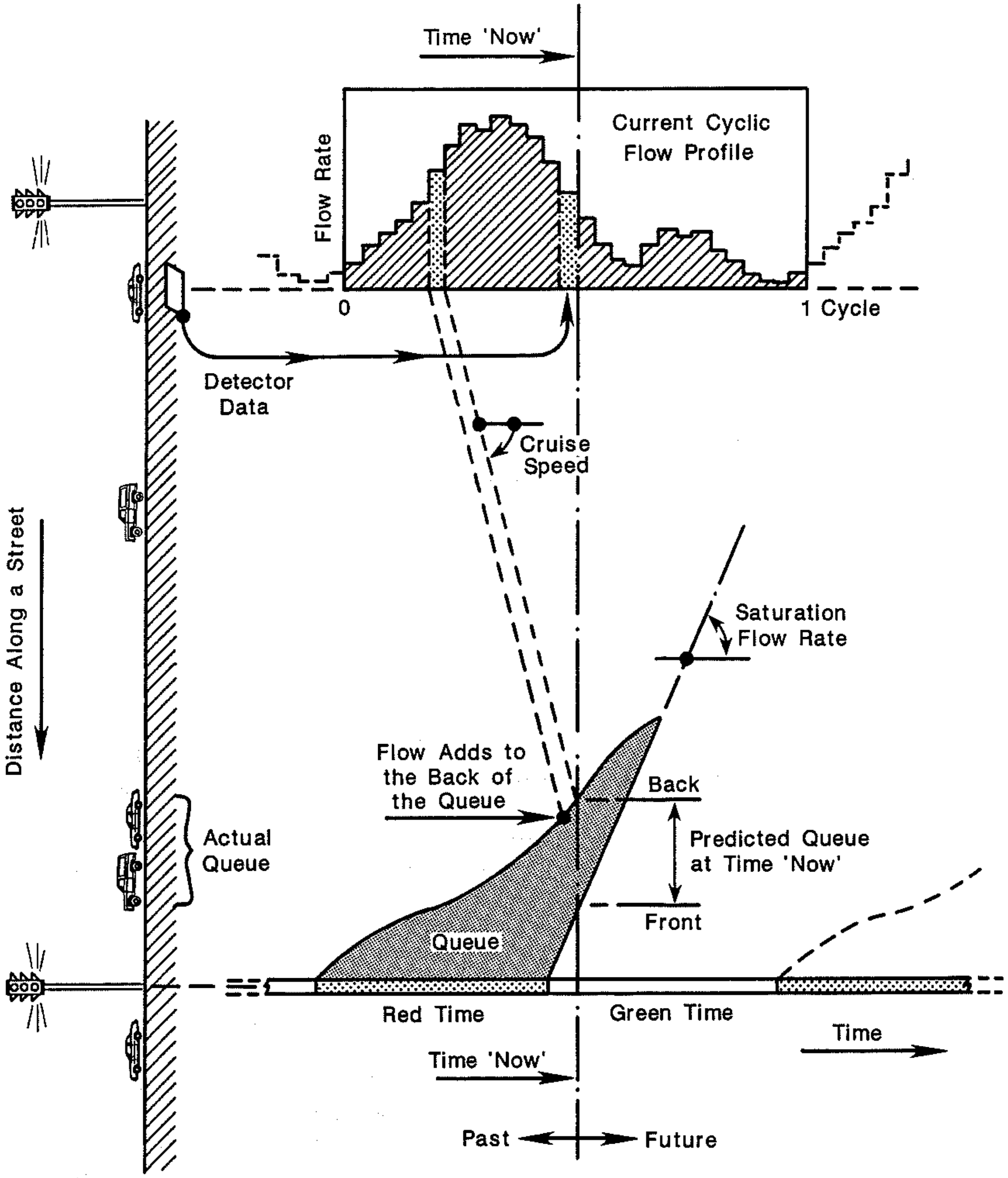

Figure 6. Principles of the SCOOT Traffic Model (9).

SYSTEM EVALUATION

The following provides a discussion on the experience of the advanced traffic control systems after implementation. This section provides background to be used when considering the effects of signal priority on the network performance.

ATSAC

An evaluation of the ATSAC system was conducted in February of 1987. The study covered the Coliseum Area which included 118 signalized intersections. The results of the study are shown in Table 2. As a result of the ATSAC system, there was a reduction of 13.2% in travel time, 3.2% in stops and 20.3% in delay (10).

A second study was conducted in June of 1991 covering three geographical areas including Westwood/West Los Angeles (combined), Ventura 1/Ventura 2A (combined), and Airport. Table 3 shows the improvements experienced as a result of ATSAC when compared to signal timing plans developed using TRANSYT-7F software, and based on static traffic volume as compared to traditional(old) timing plans. Both studies show systematic improvements in traffic flow after the implementation of the ATSAC system (11).

SCATS

An evaluation of SCATS was performed in the city of Parramatta in Sydney on a 22 signal network in 1980. Using a floating car survey, data on the number of stops, stopped time, and length of trip was recorded within the network. Data were collected over four link types: the grid network of the central business district (CBD); the arterial system comprising the Greater Western Highway (GWH); and the southern half of Church Street (CS). A performance index was calculated combining the effects of travel time and stops, as well as comparing the difference between SCATS and a fixed-time TRANSYT-optimization plan. A positive percent difference implies that SCAT was better than TRANSYT (12).

The results, as shown in Table 4, showed that for the full survey period in the CBD, SCATS was 2.6 percent better than TRANSYT in travel time and 1.2 per cent better in stops. This was not significant at the 5 per cent level however. During the lunch period in the CBD, SCATS was 6.3 per cent worse than TRANSYT in travel time and 9.1 per cent better in stops in the late period. On the less constrained arterial of Great Western Highway, SCATS consistently performed better than TRANSYT with a 4.4% difference in travel time and a 25 per cent reduction in stops. The difference in travel time was not significant at the 5 per cent level however. The survey showed that SCATS performed worse than TRANSYT during all the periods along Church Street. However, this was due to an error in the SCATS software.

Table 2. Summary of ATSAC Performance (10).

Measure of Effectiveness	Before	After	Percent Change
Travel Time (sec)	194.0	168.4	-13.2%
No. of Stops	2.92	1.89	-35.2%
Average Speed (mph)	20.2	23.2	+14.8%
Intersection Delay (sec/veh)	13.58	10.82	-20.3%
Fuel Consumption (gal/mile)	0.0709	0.0620	-12.5%
Vehicle Emissions(gr/veh-mile)			
Hydrocarbons	5.9	5.3	-10.2%
Carbon Monoxide	52.6	47.2	-10.3%

Table 3. System Evaluation Results (11).

Measure of Effectiveness	Improvement over TRANSYT-7F	Improvement over Old Timing
Travel Time	12.1%	18.1%
Travel Speed	12.3%	16.0%
Delay	32.3%	44.2%
Stops	30.4%	41.5%
Air Emissions	25.5%	34.8%
Fuel Consumptions	9.4%	13.1%

It is difficult to make an assessment of the benefits of SCATS over TRANSYT without knowing absolute numbers regarding the reduction in delay and stops. The varied success of SCATS between the time periods makes it questionable whether SCATS is an appropriate tool during periods of heavy congestion.

Table 4. Comparison of SCAT and TRANSYT-7F (7).

	Journey Time % Difference				Stop % Difference				Performance Index			
	1	2	3	4	1	2	3	4	1	2	3	4
CBD	2.6	-6.3	0.3	-0.9	1.2	-1.5	1.8	9.1*	-5.4	-15	2.3	3.1
GWH	4.4	-0.4	2.4	8.6	25*	27*	21*	26*	19	8.0	19	20
CS	26*	31*	31*	-8.6	-43*	-66*	-34*	-50*	-24*	-26*	-35*	-7.9

* Indicates result significant at the 5% level

SCOOT

In 1979 SCOOT was implemented in a 40 signal network in the central business and shopping district of Glasgow. An analysis of the system performance showed a 6 percent reduction in travel time averaged over the entire day with a corresponding delay of 12 percent at the traffic signals. Table 5 shows the results of a floating car survey conducted over a 5 week period. The analysis demonstrated that SCOOT was most effective during periods of worst congestion (9).

The performance of SCOOT was also tested in Coventry where it was installed on a 27 signal network in 1980. The results of the floating car survey are shown in Table 6. The network experienced a 5.5 percent reduction in travel time averaged over the entire day, with a corresponding delay of 2.7 per cent at the traffic signals. SCOOT was successful in reducing delay and causing fewer stops than fixed-time control systems, with absolute savings of between 3 and 22 seconds. Although statistically significant, it is questionable whether these savings could not have been achieved using a fine-tuned, fixed-time control system.

Table 5. Results of the Survey in Central Glasgow (9).

		AM Peak	Off Peak	PM Peak
Average Distance Travelled (veh km/hr)		3993	3769	4456
Time to Travel 1 km (seconds)	Fixed Time	245	302	263
	SCOOT	248	280	248
Improvement of SCOOT (%)		-1	7*	6*

* Statistically significant at the 95 per cent level

Table 6. Results of the Survey in Coventry (9).

		AM Peak	Off Peak	PM Peak
Average Distance Travelled (veh km/hr)		5228	4661	5814
Time to Travel 1 km (seconds)	Fixed Time	135	123	151
	SCOOT	128	118	139
Improvement of SCOOT (%)		5	4*	8*

* Statistically significant at the 95 per cent level

STRENGTHS AND WEAKNESSES

Each of the advanced traffic control system previously described utilizes different philosophies in optimizing cycle lengths, phase splits, and offsets. The following provides a discussion of the strengths and weaknesses of each of these philosophies.

ATSAC relies upon significant changes in traffic volume and occupancy to alert the traffic operator that a change in signal timing plan may be appropriate. SCAT relies on the degree of saturation which is measured at the stop-lines of pre-selected approaches. SCOOT relies on predicted queue lengths obtained from cyclic flow profiles and updated every cycle. The "quality" of the parameter used to determine the appropriate signal timing plan can loosely be defined as a function of how well the parameter represents changing traffic conditions, how current is its representation, and whether the parameter is predicted or measured.

ATSAC

The use of changing traffic volumes and occupancy by ATSAC is a sound approach as it reflects traffic demand and congestion and can be used to identify the location of bottlenecks and the existence of queues. This approach, however, assumes that the volume changes will persist long enough so that the new signal plan is still appropriate when it is implemented. Although small changes in volume may not warrant a new change in signal plan, delaying the change in signal plan until large volume changes occur may result in deteriorated traffic conditions when the new signal plan is introduced. ATSAC satisfies the loosely defined definition of using "good" parameter in terms of its use of measured, rather than predicted, flows.

Some of the problems associated with the use of changing traffic volumes can be eliminated utilizing critical intersection control. Twenty-five percent of the ATSAC network is under critical intersection control. Under this control, the phase splits are adjusted on a cycle by cycle basis using real-time traffic demand. Although offsets and cycle lengths remain the same, this approach eliminates the lag in time associated with using changes in traffic volumes as the decision parameter.

SCATS

The degree of saturation, as used by SCATS, is an effective parameter for describing traffic conditions at an approach. The parameter directly identifies the level of traffic compared to the capacity of the approach. The degree of saturation is measured from real-time data and does not rely on predicted values. This parameter seems to satisfy the stated definition of using a "good" parameter in all three respects.

SCOOT

SCOOT, like SCATS, relies upon the degree of saturation to determine the appropriate signal timing plan to be used. SCOOT, however, estimates the degree of saturation using measured flows and a pre-determined value of saturation flow. The "quality" of this parameter in accurately representing traffic conditions depends upon the accuracy of the estimation of the saturation flow. SCOOT does utilize real-time traffic data in the form of cyclic flow profiles which are updated each cycle.

SCOOT also relies on predicted queue lengths to determine phase splits and offsets. Using queue lengths as a parameter is a very good estimator of delays. Therefore, although the parameter is predicted, the use of queues to determine signal timing plans is effective because minimizing queue lengths also minimizes the number of stops within the network.

SIGNAL PRIORITY IMPLEMENTATION

The previous discussion demonstrates that advanced traffic control systems can reduce delays and stops compared to fixed-time systems. The following discusses the ability and experiences of these traffic adaptive systems in providing signal priority.

UTCS-1st Generation, Washington, D.C.

One of the earliest implementations of signal priority utilizing advanced traffic control systems was a demonstration project sponsored by the Federal Highway Administration in 1972. The Urban Traffic Control System/Bus Priority System (UTCS/BPS) was tested on a network of 114 signal controlled intersections within the central area of Washington, D.C. and along two primary arterials. A total of 343 approaches were under UTCS surveillance with 72 "bus detectors" located along those arterial streets carrying significant bus traffic. Of approximately 2,200 buses operated by the local transit company, 450 were originally equipped with special transmitters. Of these 450, only 300 were operational at the time of the study (13).

Using transmitters, bus priority was provided by either extending the green phase or truncating the red phase. When the bus cleared the intersection, the signal returned to its normal phase durations. The system measured traffic volumes at the intersection and inhibited the bus priority system if the intersection became oversaturated. Table 7 shows the results of introducing bus priority across the entire network.

The table compares vehicle minutes of delay under bus priority to the base case where time-of-day plans were developed off-line using TRANSYT-7F and selected automatically based on on-street traffic conditions. The table demonstrates that during the A.M. study period, links with high BPS activity experienced a reduction in delay while those with medium or low activity experienced increases in delay. The off-peak direction was helped nearly as much as the peak direction under high activity. Under medium to low activity, the off-peak direction was only moderately helped and the peak direction experienced increases in delay. Both the opposing and cross links were worse under BPS. During the PM study period, link flows are worse for both the opposing and cross links.

An evaluation was performed to determine the effect of BPS on bus travel times. At the intersection of 18th and Pennsylvania, delay increased by 19.1% for northbound buses in the AM peak period. This delay was attributed to pedestrians who used the extended green to cross and impeded the right-turning northbound buses on Pennsylvania Avenue. At 14th and K Street, there was a significant decrease in delay for detector-transmitter equipped buses when compared to non-equipped buses. Although high volumes of pedestrians were also present at this intersection, buses using this intersection travel through the intersection and were therefore able to use all of the priority phase.

Table 7. Vehicle Minutes of Delay Averages for BPS Intersection Approaches (13).

BPS Activity	Bus Flow Direction	A.M.			P.M.		
		Link	Opposing Link	Cross Links	Link	Opposing Link	Cross Links
High	Peak	+5.8	+5.6	-8.3	+0.5	-7.0	-0.8
		(9)	(7)	(11)	(2)	(1)	(4)
	Off-Peak	+5.0	-1.3	+2.8	-6.0	+15.3	-6.5
		(7)	(4)	(4)	(6)	(3)	(6)
Medium	Peak	-10.8	-3.5	-27.0	-4.8	+6.3	+4.2
		(4)	(2)	(2)	(5)	(3)	(6)
	Off-Peak	+3.0	-11.0	-19.0	-2.0	+10.0	-1.0
		(2)	(2)	(1)	(4)	(1)	(4)
Low	Peak	-23.4*	-0.5	-15.9*	+3.3	+2.3	+3.0
		(8)	(4)	(8)	(3)	(4)	(2)
	Off-Peak	+4.5	-29.5*	-2.0	-3.3	N.A.	-9.5
		(4)	(4)	(1)	(3)	(0)	(2)

Notes:

- Data shown are average differences per link, positive values indicating less delay with BPS.
- Number of links (sample size) in parentheses.
- Values assigned to peak direction if bus flow exist both ways.
- Indicates inclusion of very large change in delay for Link 190.

A third intersection at Wisconsin Avenue and Macomb Street was examined in determining the effect of BPS on bus travel time. This intersection differed from the previous two in that it was representative of a collector street crossing a principal arterial with bus traffic on the arterial. The study showed an overall time reduction of 7.0% for instrumented buses when compared to non-instrumented buses at this intersection.

The study concluded bus priority worked well when offset was not extremely critical, such as in a closely spaced grid network. Priority was successful in reducing bus delays on a given approach by as much as 35% and on a given route by 6%. These savings did not come at the expense of the network with small increases in delay of 0.03 and 2.5 percent. The study also identified that in areas of high bus activity (30 to 50 buses per hour), as well as at congested intersections, improvements to bus travel were limited. This may be attributed to the fact that the continuous triggering of priority for locations with high bus activity could result in overall timing allocations that are inferior to those of the base signal timing plan.

ATSAC - Los Angeles, California

The ATSAC system provides flexibility in the traffic signal operation which allows various levels of signal priority to be provided to the Los Angeles light rail system. The Los Angeles light rail system extends for 22 miles between downtown Los Angeles and downtown Long Beach. The double track system has 20 stations, crosses 85 roadways at-grade and has a peak headway of 6 minutes. The LRT operates in a street running mode in the downtown sections of the line with the tracks located in the median of two-way streets and to the side of one-way streets. The LRT crosses 47 roadways at-grade which are not equipped with gates, bells or flashers due to space limitations in the downtown environment. Preemption is not provided for the LRT in the downtown segments; however, the LRT is able to receive priority at some intersections at certain times of the day (14).

The ATSAC traffic control system presently controls 16 of the intersections crossed by the LRT system from west of Los Angeles Street along Washington Boulevard and five of the intersections on Flower Street alignment. Partial priority is provided in the form of window stretching which allows the green window provided for the LRT-phase to either start earlier than normal, or finish later than normal. The green time used to widen the LRT phase is taken from other phases; however, this extra length of the LRT phase is limited, and no phase with a demand would be skipped in any cycle. Full priority is also provided to the LRT by altering the signal operation to favor the LRT movement in the presence of the LRT. This priority treatment may result in the shortening of some phases and skipping of other phases to accommodate the LRT.

Flexibility exists in whether full-, partial-, or no-priority operation is provided as well as when these priority techniques are implemented either by time-of-day, vehicle response, or manually. This flexibility avoids severely impacting the cross-street traffic at times and locations when the intersection could not successfully provide priority.

Adjusting the type of priority by time-of-day may result in little or no priority during the peak hours and full or partial priority during the off-peak hours. Using vehicle response as an indicator to adjust priority levels involves the use of vehicle detectors to determine when significant queues are present. The level of priority can be reduced or deactivated once excessive traffic queues are detected. Manually adjusting the type of priority can be done either at the controller cabinet or from the traffic signal control center.

Implementation. The implementation of priority on the Los Angeles-Long Beach LRT system has been postponed as a result of delays in the software development. It has been demonstrated, however, through a bus priority demonstration project that priority could successfully reduce vehicle delays under traffic conditions and intersection geometry similar to those along the LRT line. The City of Los Angeles, Department of Transportation, and the Southern California Rapid Transit District performed a bus priority traffic preemption demonstration project along a ten mile section of Ventura Boulevard in June of 1983. On the buses, priority was provided using emitters which transmitted optical signals to the traffic signal controller at 49 intersections to either extend the green or advance the major street green phase for up to 10 seconds (15).

The system was evaluated using on-board bus travel time and delay surveys as well as direct travel time measurements at two locations. Table 8 shows the results of this study for the two bus lines studied, Line 424 and 425. On the average, priority resulted in savings to bus riders of 3.2 minutes (or 4.2% reduction) for a 77.1-minute round trip bus trip. Bus delays at signalized intersections were reduced by 21.6% from 10.2 minutes to 8 minutes.

Table 8. Ventura Bus Lines Under Priority (15).

MEASURE	Line 424			Line 425	
Reduction in	AM	MD	PM	AM	PM
Avg. Tot. Travel time	4.3%	3.1%	4.9%	1.5%	6.2%
Avg. Signal Delay	34.9%	16.0%	23.4%	25.8%	13.2%

This project operated outside of an adaptive traffic control system. It is anticipated that implementing a similar priority scheme in an adaptive traffic control system would result in savings not only to the buses but in minimized delays to the cross-street traffic.

SCATS - Melbourne, Australia

As a result of government attempts to improve public transit in Melbourne, Australia, the city introduced tram priority for its 250 km tram network. Utilizing the strategic control available through SCATS and the tactical control flexibility of the microprocessor, 180 sets of signals in Melbourne were coordinated and public transit priority was provided (16).

Figure 7 shows a typical intersection under SCATS control, including the location of selective tram detectors which are used to determine the demand for priority phases. Figure 8 shows the priority phases including an extension Phase B and three early start phases D1, D2, and D3. The early start phases include a turn phase from either direction(D1,D2) or a two-way early start phase option (D3). The advance detector places calls for either an early start phase to allow turning vehicles to clear the path ahead of the transit vehicle, or to place calls for the phase extension (Phase B). The stop-line detector places calls for the extension phase during Phase A, as well as for early start phase D3 during Phase C.

Implementing priority within a coordinated signal system is facilitated by several features available through SCAT system control. The first is the ability to monitor the degree of saturation on a cycle-by-cycle basis to identify critical approaches. Delays that occur on the cross-street as a result of providing priority to the main street can be detected through this monitoring and minimized using dynamic compensation. Dynamic compensation helps restore balance between the approaches of competing flows.

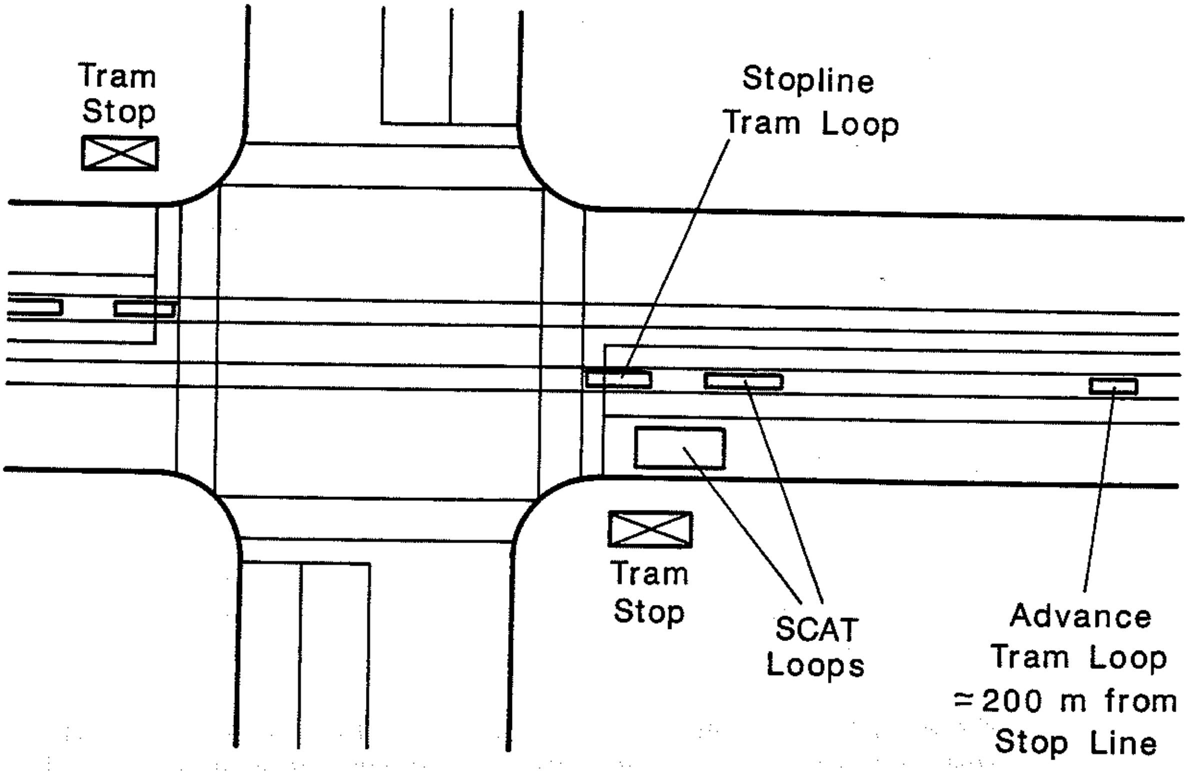

Figure 7. SCATS Controlled Intersections (16).

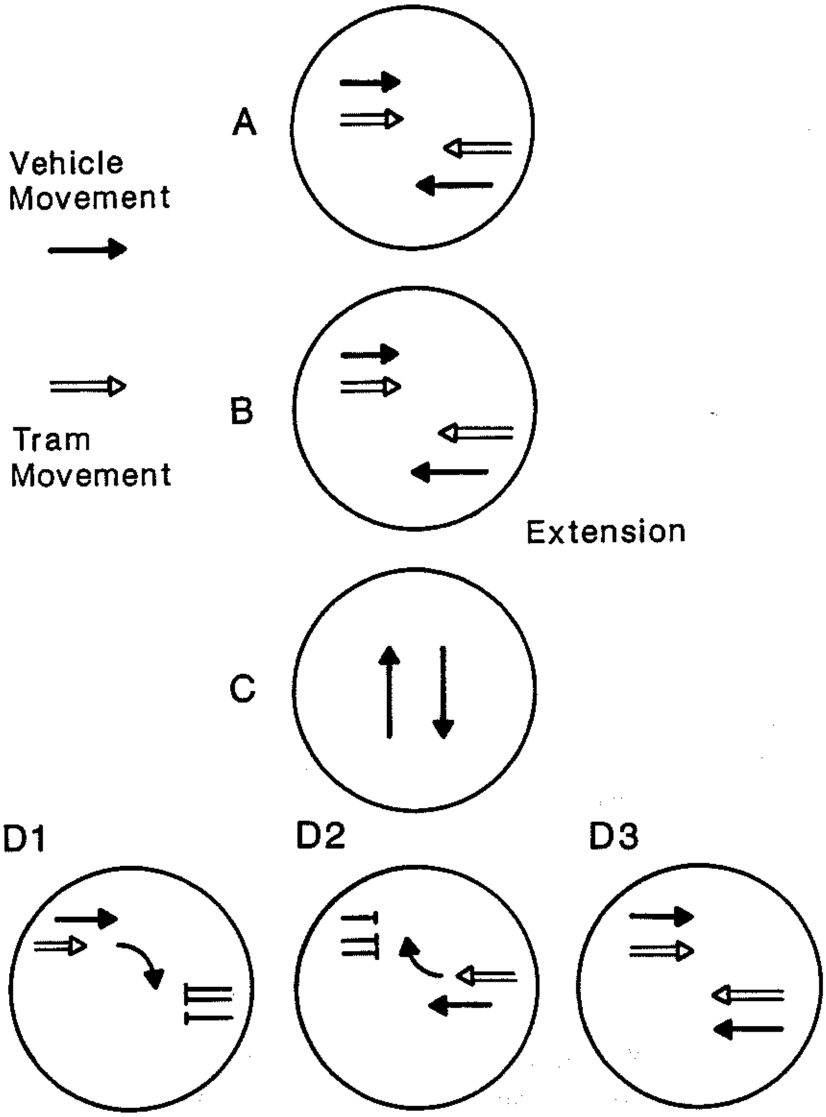

Figure 8. Priority Phases (16).

A second element provided under SCATS is flexible window stretching. SCATS's systems algorithms provide time transfer between priority phases in the form of Time Gain (TG) or False Green (FG). Time gain absorbs time in the current cycle not used by previous phases and False Green uses time allocated to a subsequent phase if not called. The objective of this scheme is to provide priority at any point in the signal as required by the transit vehicle.

The third element of SCATS control is its flexibility in the strategic selection of the priority phase. The options for which priority phases are selected include a time of day selection, which provides particular priority phases during peak hours; tidal flow selection which is based on traffic flow demand; and intersection congestion selection, which enables priority turn phases along the approaches experiencing the heaviest congestion in terms of delay. The selection of the appropriate priority phase using intersection congestion is not only traffic responsive, but it is also sensitive to traffic conditions in the minor flow direction and can respond to increasing congestion along these approaches.

Implementation. The above priority scheme was implemented along two parallel tram routes and three cross routes in a suburb of Melbourne, Australia. Travel times were recorded during the peak hour in the peak direction along the studied routes. The study looked at the effects of implementing both signal coordination and active priority along the routes. Along a portion of some of the routes, passive priority was also implemented in the form of exclusive tram lanes during specified time periods of the day.

The differences in travel times before and after the implementation of tram priority are recorded in Tables 9 and 10. The overall results of the study revealed that due to signal priority, there was a reduction in travel time for both trams and cars travelling in the same direction. This reduction, however, was statistically significant for trams only. Cross street traffic also experienced reduction in travel time as a result of signal coordination in an active priority environment. Only at Bell Street in the AM peak hour was there a significant increase in travel time.

SCOOT - Teesside

Signal priority in SCOOT can be provided through the use of weighting factors which are used to alter the actions of the optimizers to favor traffic on specified links. This technique utilizes both split and offset weighting (17).

To provide coordination, signals within the SCOOT network must operate at uniform cycle lengths or half the cycle length in the case of double cycling. As a result, some intersections whose traffic volumes do not warrant the network cycle length will operate with extra capacity. Split weighting gives this spare capacity to the priority route and thus improves traffic flow along these routes.

Table 9. Travel Times in Peak Direction/Peak Hour (15).

Route		Mean Travel Time (min.)		
Tram		Before	After	% Difference
E. Preston	A.M.	37.1	35.0	-6*
	P.M.	28.8	27.0	-6*
W. Preston	A.M.	34.7	31.2	-10*
	P.M.	34.2	31.0	-9*
Car		Before	After	% Difference
E. Preston	A.M.	29.0	27.0	-7
	P.M.	33.1	32.7	-1
W. Preston	A.M.	26.6	24.8	-7
	P.M.	25.7	25.4	-1

* Significant at the 95% level

Table 10. Car Travel Times Across Priority Routes (15).
(Peak Direction/Peak Hours)

Cross Route		Mean Travel Time (min.)		
Car		Before	After	% Difference
Johnston St.	A.M.	3.37	2.00	-41*
	P.M.	2.68	2.56	-4
Separation St.	A.M.	5.61	4.90	-13*
	P.M.	5.14	5.26	2
Bell Street	A.M.	4.01	4.52	13*
	P.M.	4.46	4.16	7*

* Significant at the 95% level

The split optimizer under split weighting is given a weighting factor as well as a target saturation for the weighted links usually at about 90 to 95 percent. Under normal operation, the SCOOT split weighting optimizer minimizes the delay at the intersection by balancing the degree of saturation at each approach. When split weighting is utilized, the delay on the weighted links will rise, and the delay will be reduced on the favored links.

Offset weighting is also used to provide priority along a specific route. The offset weighting is an integer that is multiplied(one-tenth of the integer) by the flow on the link to increase the importance of that link to the optimizer. For example an offset weighting of 15 will cause the flow on the link to be multiplied by 1.5.

To better understand the effects of weightings, a simulation using different sets of weightings as well as a limited on-street test, was conducted. The simulation utilized a microscopic model which simulates individual vehicles and calculates the delay for every vehicle on each link. The results of the simulation indicated that although offset weighting reduced the delay on the weighted links at low flows, under high flows there was an overall increase in delay for the network, as well as on those links which should have benefited. Under low- and medium-flow conditions, split weighting decreased delay to the benefiting links and had uncertain effects under high flows.

Implementation. The effects of the use of weightings to favor a bus route were tested on a limited on-street test in Teesside. The survey was performed along a bus route where 11 of the intersections were SCOOT controlled. Of these 11 intersections six were identified as suitable for split weighting, three for offset weighting, and one for both split and offset weighting. The target degrees of saturation were set to 95 per cent with the split weights varying between 2 and 16 and the offset weights at 30.

Data on the delay experienced by buses at the SCOOT controlled intersections were collected from two sources: instrumented buses and the SCOOT model. Five buses were instrumented for collecting data. The overall benefits measured by the buses are shown in Table 11. The table demonstrates that the overall benefits measured by the buses were small at all times of the day. Some of the measurements included delays that were larger-than-average and were not due to weightings. These outlying data points were removed and the results are shown in Table 12. Although the overall benefits to the buses are still small, the percentage reduction in the off-peak and PM peak is appreciable.

The SCOOT model is able to give estimates of the effects on traffic of the split and offset weightings. The results of this analysis is shown in Table 13. The SCOOT model shows similar results as measured by the on-street test where a small, but not statistically significant, reduction in delay was experienced at all periods of the day. To account for increasing delay as a result of increase in flow, a regression analysis was performed correlating the total delay to all vehicles and the total flow in the network. Table 14 shows the effects of the priority after flow weightings. In the AM peak, SCOOT estimated an overall benefit but was detrimental in terms of delay per vehicle in the off-peak and PM peak periods.

Table 11. Measured Reduction in Delays to Buses (17).

Period	Total Reduction per Round Trip (sec.)	Percentage Reduction	Average Reduction per Junction (sec.)
AM peak	39	8%	2.0
Off-peak	23	5%	1.2
PM peak	33	6%	2.0

Table 12. Reduction in Delays to Buses After Removing Outlying Data Points (17).

Period	Total Reduction per Round Trip (sec.)	Percentage Reduction	Average Reduction per Junction (sec.)
AM peak	15	3%	1.0
Off-peak	44	10%	2.4
PM peak	77	14%	4.3

Table 13. Mean Delay Per Vehicle Per Junction (17).

Period	Without Weightings (sec.)	With Weightings (sec.)	Change Percentage
	BENEFITING LINKS		
AM peak	36.1	34.1	-5.9
Off-peak	30.3	28.4	-6.6
PM peak	45.0	43.4	-3.7
	DISBENEFITING LINKS		
AM peak	41.1	41.0	-0.04
Off-peak	29.1	34.4	15.4*
PM peak	45.9	50.6	9.2*

* Statistically significant at the 5 per cent level

Table 14. Change in Network Delay
Due to the Weightings (17).

Period	Benefiting Links	Disbenefiting Links
Am Peak	-3.75	-0.13
Off-Peak	-3.26	5.71
PM Peak	-3.19	5.94

Strengths and Weaknesses

Signal priority for transit operations introduces signal timing plans that are not optimal for traffic flows. One philosophy for introducing signal priority is to operate under optimal signal timing plans when the transit vehicle is not present and to temporarily alter this signal timing plan when signal priority is introduced. ATSAC and SCATS operate under this philosophy. ATSAC uses window stretching which provides either an early start or delayed green for transit vehicles. SCATS utilizes a similar treatment of flexible window stretching which reassigns the unused priority phase to either the early start or extension phase. Both window stretching and flexible window stretching are active priority treatments which provide priority in the presence of the transit vehicle.

SCOOT, on the other hand, provides passive priority, increasing the green time for movements serving the transit vehicle. This approach provides continuous priority and does not detect the presence of the transit vehicle. However, the adaptive capabilities of SCOOT assure that the degree of saturation is maintained at a specified level for all approaches to intersections receiving priority treatment, providing continuous priority results in the implementation of non-optimal signal timings for the current traffic condition.

EVALUATION OF CROSS-STREET TRAFFIC

The above discussion demonstrates that signal priority for transit operations can be provided using advance traffic control systems. These control systems also have the advantage of being able to provide the needed monitoring within the network to minimize delays to the cross street traffic which are penalized when priority is provided. The following provides a discussion on how each of the advanced traffic control systems monitors traffic conditions on the cross-street approaches.

ATSAC

Under vehicle response control, ATSAC monitors the development of queues on the cross-street. Manual control, which is typically provided on a temporary basis to respond to unusual traffic occurrences, monitors congestion on all approaches to the intersection. Under time-of-day control, little or no priority may be provided in the peak periods when volumes on the cross-street are typically the highest. As a result, queues on the cross-street are minimized by selection of appropriate levels of priority. This control strategy, however, does not monitor traffic conditions on the cross-street, and the potential does exists for the cross-streets to be oversaturated.

SCATS

Dynamic compensation is a direct measure provided by SCATS aimed at minimizing delays to the cross-street traffic. This mechanism involves the selection of phases favoring the non-priority movements after priority is provided. SCATS is also sensitive to cross-street traffic providing priority to the approach experiencing the heaviest congestion. Using the degree of saturation, SCATS is able to enable those phases that favor the direction with the highest level of congestion.

SCOOT

SCOOT does not have a separate algorithm to compensate the cross-street traffic when priority for transit operation is provided. The operation of SCOOT, however, is sensitive to the degree of saturation along all approaches to SCOOT controlled intersections.

CONCLUSION

Advanced Traffic Control Systems have several advantages over fixed-time systems in managing traffic as well as in implementing successful signal priority schemes. These systems are better able to handle daily fluctuations in traffic flow including those caused by non-recurring traffic conditions. Advanced traffic control systems can implement signal timing plans that evolve over time with the traffic demand. Although more expensive to install than fixed-time systems, advanced traffic control systems can be justified in terms of the reduction of delay, stops, and fuel consumption.

Signal priority has been demonstrated to improve transit operations. Under fixed-time control, signal priority is implemented at the expense of cross-street traffic. Under adaptive control systems, the penalties associated with signal priority are spread throughout the network, however, these penalties are not as high as those associated with fixed time control.

It is difficult to make an assessment of ATSAC, SCATS and SCOOT on their success in implementing signal priority. What this study has identified is that the flexibility provided through the use of these systems is advantageous when compared to fixed-time systems. The flexibility in signal plan selections and their ability to monitor traffic conditions make them tools that should be looked at in closer detail by public transit agencies.

RECOMMENDATIONS

A. Pedestrians need to be accounted for in determining the level of congestion at the intersection.

Although it can be demonstrated that advance traffic control systems can successfully implement signal priority systems, these systems neglect several human factors that may limit their growth in central business districts. The advanced traffic control systems discussed above utilize a logic in determining phase splits that underestimate the effect of pedestrians at the intersection. In adjusting the phase splits in all three systems, the minimum phase lengths account for pedestrian walk times. The models, however, do not account for pedestrians who may conflict with some permitted movements and thus are underestimated in determining the level of congestion at the intersection.

B. Phase sequencing standardizing needs of to minimize confusion on the part of motorists.

A second area requiring further investigation is the violation-to-driver expectation when implementing a non-standard sequencing of signal phases under signal priority. Because signal priority under advanced traffic control can potentially generate a unique sequence of phasing during each cycle, motorists are not able to expect the sequence of phases at the signal. This may result in some confusion on the part of motorists, which may lead to accidents and may require that the logic used by advanced traffic control systems rely on standardizing the phase sequence.

C. Priority should be selectively assigned to discriminate between peak and off-peak transit vehicles as well as on-time, early, and late transit vehicles.

Because providing two-way priority for both peak and off-peak transit vehicles has limited success, it may be necessary to allow priority in only one direction. Some may argue that priority should not be provided for off-peak vehicles which are "dead-heading" or returning to the origin of the route virtually empty. The other side of the argument is that reducing the time required for these vehicles to return to the origin of the route can result in savings because of a smaller vehicle fleet size.

One purpose of signal priority is to reduce the variation in travel times of public transit vehicles and thus allow these vehicles to better maintain travel schedules. As a result, providing priority to early transit vehicles undermines this goal, causing transit vehicles to run ahead of schedule. The logic used in determining if priority is appropriate should therefore take into account the time schedule of the transit vehicle.

D. The frequency of transit vehicles is key in determining the success of signal priority.

The frequency of transit vehicles has a significant impact on the success of providing priority especially in congested downtown grid networks. The demonstration project in Washington, D.C. demonstrated that during the A.M. peak hour, links with high bus priority activity experienced a reduction in delay, while those with medium or low activity experienced increases in delay. This may be attributed to the fact that a high frequency of bus activity results in a wider bandwidth and therefore better progression. Therefore, as the frequency of transit vehicles increases along a particular corridor, traffic control systems should determine whether priority should continue to be provided.

E. Prediction of the arrival of the transit vehicle to the traffic signal should be incorporated into models.

Under traffic-adaptive control, priority phases are incorporated into the signal plan after receiving an indication of the presence of the transit vehicle. The locations of the advance detectors for each of the advanced traffic control systems are generally near the upstream intersection. The abrupt intrusion of the priority phase into the signal plan during the time the transit vehicle is detected and the vehicle reaches the downstream signal can result in increases in delay across the entire network.

The use of prediction to determine the time of arrival of the transit vehicle to the traffic signal is one way of better integrating priority phases into the signal plan. This would require that the transit vehicle be detected at all points through the network so that the predictions could be updated. The advanced traffic control system could use this information to favor the progression of the transit vehicle.

FURTHER RESEARCH

1. Researchers need to determine at what levels of transit activity should priority be provided as the vehicle is detected, and when should this level of priority be expanded so continuous priority is provided across a specified network.

2. Compensation has been proposed as a means of reducing delays to the non-priority movement. There is little research, however, on the additional green time requirements for returning the non-priority movements to a traffic conditions prior to the implementation of the priority treatment.

3. One of the findings of the Washington D.C. demonstration project was that at short block spacings under congested conditions, buses could not utilize signal priority because of queues which extended from the downstream intersection. Studies need to be performed to determine at what block spacings would priority be unsuccessful in reducing delays to transit vehicles.

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Janice Daniel received her B.S.E. in Civil Engineering from Princeton University in June 1985 and an M.S. in Transportation Engineering from Polytechnic University in May 1989. She has worked as a traffic engineer for the Port Authority of NY & NJ for four years and as a transportation engineer for the consulting firm of Philip Habib & Associates for two years. She is presently working toward a Ph.D. and is currently employed as a Graduate Research Assistant by the Texas Transportation Institute. Her areas of interest include: traffic operations and modelling.