Traffic Signal Control

- Introduction
  - What is Traffic Signal Control?
  - The Rationale for Traffic Signal Control
- System Description
  - Terminology
  - Scope of Control
  - Modes of Operation
  - Offline Signal Timing Optimization Models
  - Adaptive Control Strategies
  - Standard Traffic Controllers
- Assessment
  - Key Results
  - Benefits
  - Costs
  - Implementation Challenges
- Where is Traffic Signal Control implemented?
- Case Studies
  - Los Angeles, CA: Automated Traffic Surveillance and Control (ATSAC)
  - Oakland County, Michigan: Faster and Safer Travel through Traffic Routing and Advanced Controls (Fast-Trac)
  - Anaheim, CA: Field Operational Test with SCOOT
- References

INTRODUCTION

What is Traffic Signal Control?

Traffic signal control is a system for synchronizing the timing of any number of traffic signals in an area, with the aim of reducing stops and overall vehicle delay or maximizing throughput. Traffic signal control varies in complexity, from simple systems that use historical data to set fixed timing plans, to adaptive signal control, which optimizes timing plans for a network of signals according to traffic conditions in real-time.

The Rationale for Traffic Signal Control

As population continues to grow, the demand on our existing transportation system will become increasingly hard to meet. Roads and highways are unlikely to expand much due to cost and dwindling land supply, so intelligent systems such as advanced traffic signal control will be critical to operating our current roadway systems at maximum capacity. Furthermore, poorly timed signals can waste time, fuel, and money. In a street network with poorly timed traffic signals, the fuel consumed by vehicles stopping and idling accounts for approximately 40% of network wide vehicular fuel consumption [8].

Traffic signal improvements generally provide the greatest payoff for reducing surface street congestion when compared with other methods, such as widening roads [12]. Advanced traffic signal control can help ease congestion and its negative externalities without the cost and environmental impact of road expansion.

SYSTEM DESCRIPTION

Terminology

Traffic signal operation can be described in terms of cycle length, signal phases, and offsets. A traffic signals' phasing plan defines how the signal operates. Phasing plans can be simple, two-phase plans (one phase per approach) or can be tailored to allow protected/permitted movements and lead/lag phases. An intersection with heavy left turning traffic and heavy opposing through movements would probably include a protected left turn phase either before the opposing traffic is released (lead phase) or after the opposing traffic is stopped (lag phase). The cycle length is the total time required for a complete sequence of signal phases and is typically between 60 to 120 seconds for a four-legged intersection. The offset between successive traffic signals is the time difference between the start of the green phase at an upstream intersection as related to the start of the green phase at an adjacent downstream intersection. See our Telecommunications Diagrams on Adaptive Signal Control and Fixed Signal Control for more information.

Scope of Control

Traffic signals may operate independently, or as a system. The scope of control can be grouped in 3 categories:

- **Individual Intersection Control –** A single traffic signal operates in a pre-timed, actuated, or traffic responsive mode, without affecting the operation of other traffic signals.

- **Arterial Control –** Two or more traffic signals operate synchronously along an arterial street in a pre-timed progression, traffic responsive, or adaptive control mode.

- **Network Control –** Traffic Signals throughout an entire network of intersections are coordinated through a timing plan created offline, or an adaptive control strategy.

Modes of Operation

There are many different levels of traffic signal control, from the individual intersection with pre-timed control to the network-wide system with adaptive control. Here are descriptions of the different modes of operation, from the simplest to the most complex:

1. **Pre-timed**- Under pre-timed operation, the master controller sets signal phases and the cycle length based on predetermined rates. These rates are determined from historical data. Pre-timed signal control is appropriate for areas where traffic demand is very predictable.

2. Progression Schemes - A progression scheme is a simple way of coordinating signals along an arterial, which is common in many urban areas. The signals can be set manually to run in a constant, synchronous manner. There are 3 different types of progression schemes:

Simultaneous - Under simultaneous progression, all signals along the route operate with the same cycle length and display green at the same time. All traffic moves at once and a short time later all traffic stops at the nearest intersection to allow cross street traffic to move. This type of progression is typically used in downtown areas where intersections are close together, 300 to 500 ft, and uniformly spaced.

Alternate - For alternate progression, there is a common cycle length, however each successive signal or group of signals shows opposite indications. This type of progression is associated with uniform spacing of intersections. Ideal spacing is in the range of 1000 to 2,000 feet.

Limited or simple - Limited/simple progression schemes employ a common cycle length, though the relationship of the indications between intersections vary because spacing between intersections is not uniform, and therefore offsets at each intersection differ. This type of progression scheme is typically used where traffic flow is uniform throughout the day.

Flexible - Flexible progression schemes are identical to simple progression schemes, except that the common cycle length can be changed to reflect changing traffic patterns. Similar to limited or simple progression schemes, flexible progression schemes use different offsets between intersections.

3. Actuated - An actuated controller operates based on traffic demands as registered by the actuation of vehicle and/or pedestrian detectors. There are several types of actuated controllers, but their main feature is the ability to adjust the signal's pre-timed phase lengths in response to traffic flow. If there are no vehicles detected on an approach, the controller can skip that phase. The green time for each approach is a function of the traffic flow, and can be varied between minimum and maximum lengths depending on flows. Cycle lengths and phases are adjusted at intervals set by vehicle actuation of pavement loops.

•□□□□□□□□ **Semi-Actuated Control**- A semi-actuated controller provides for traffic actuation of all phases except the main phase. A continuous green is maintained on the major street except when a demand is registered by the minor street detector. The right of way always returns to the major street when no vehicles are present on the minor street or a timing limit has been reached. Semi-actuated operation is best suited for locations with low volume minor street traffic. It may also be used to permit pedestrian crossings at mid street.

- **Full Actuated Control-** Under full actuated control, the function of the controller is to measure traffic flow on all approaches to an intersection and make assignments of the right of way in accordance with traffic demand. Full actuated control requires placement of detectors on all approaches to the intersection. The controller's ability to respond to traffic flow provides for maximum efficiency at individual locations. This type of control is appropriate for intersections where the demand proportions from each leg of the intersection are less predictable.

4. Traffic Responsive - In traffic responsive mode, signals receive inputs that reflect current traffic conditions, and use this data to choose an appropriate timing plan from a library of different plans. An individual signal or a network of several signals may be traffic responsive. Capabilities include:

- **Vehicle Actuated** - uses data from presence detectors and modifies the phase splits based on vehicle actuation and gaps. This procedure addresses current traffic and does not require traffic projections.

- **Future traffic prediction** - control system uses the volume data from system detectors and projects future conditions.

- **Pattern Matching** - the volume and occupancy data from system detectors are smoothed and weighted and compared with profiles in memory. This enables identification of the stored profile most closely matching the existing traffic conditions. When a pattern is identified, appropriate parameters are placed into operation.

5. **Adaptive Control Strategies (ACS) -** these systems are currently the most advanced and complex control systems available. They are similar to traffic responsive signals in that they receive real-time data through detectors, but instead of matching current conditions to an existing timing plan, the system uses an online computer to create an optimal timing plan. No library of timing plans is needed, which works well for areas with high rates of growth, where libraries of timing plans would need to be updated frequently.

Offline Signal Timing Optimization Models

As computer technology has improved, computer models have replaced manual setting and optimization of signal timing plans. These powerful models use historical data and computer simulation to create an optimal signal timing plan that either maximizes bandwidth or minimizes total delay. The basic ingredients of these models include (a) a traffic flow model, and (b) an algorithm for optimizing a specified performance criterion. The following are examples of signal timing optimization programs that are available either in the public domain, or from private companies [3, 4]:

- **Urban Traffic Control Systems (UTCS)**-UTCS is a centralized traffic control system that controls all intersections in a system with fixed or variable timing plans. UTCS was developed by the Federal Highway Administration in the 1970's as part of a research project that sought to develop and test a variety of advanced network control concepts and strategies. Historical data based on time of day and day of week are often the basis of the plan. Some UTCS provide critical intersection control (CIC), a feature that allows vehicle actuated adjustments of green time splits at selected signals. The control strategies in the UTCS project are categorized into three generations; the first generation is an offline optimization tool, described below, and the other generations are online tools, which will be discussed in the next section.

First Generation Control (1-GC) - 1-GC control uses pre stored signal timing plans that are calculated off-line based on historic traffic data. The timing plan can be selected on the basis of time of day, by direct operator selection, or by matching from an existing library a plan best suited to recently measured traffic conditions in traffic responsive mode. Under traffic responsive mode, the software updates the plan every 15 minutes with a smooth transition between regimes. 1-GC has the CIC feature described above.

- **SOAP** - SOAP provides a macroscopic analysis with the primary objective of developing signal control plans for individual intersections. It develops cycle lengths and splits that minimize a performance index. Inputs include traffic flows, truck and bus composition, left turn data, saturation flow, and signal data. Outputs include delay, percent saturation, queues, excess fuel consumption, left turn conflicts, and percent stops.

- **Traffic Network Study Tool (TRANSYT)** -TRANSYT is one of the most widely used signal timing programs. The original version of TRANSYT was developed by the Transportation and Road Research Laboratory in England in 1968. Though TRANSYT is most commonly used as an offline optimization tool, it may also be used in an online fashion to compute signal settings every few minutes and download these settings to the field. TRANSYT is a macroscopic, deterministic simulation and optimization model. The model requires the link flows and link turning proportions as inputs and assumes them to be constant for the entire simulation period. The program optimizes splits and offsets given a set cycle length and carries out a series of iterations between its traffic simulation module and the signal setting optimization module.

A version tailored specifically for the United States was created, entitled TRANSYT-7F. The TRANSYT-7F program is capable of evaluating a coordinated network or arterial of up to 50 intersections with up to 250 directional links.

- **MAXBAND -** MAXBAND is a bandwidth optimization program that calculates signal timing plans on arterials and triangular networks. MAXBAND produces cycle lengths, offsets,

speeds, and phased sequences to maximize a weighted sum of bandwidths. The primary advantage of MAXBAND is the freedom to provide a range for the cycle time and speed. The lack of incorporated bus flows and limited field tests are disadvantages of MAXBAND.

- **PASSER II-80** - PASSER II-80 is a bandwidth optimization program that calculates signal timing plans on linear arterials. A modified version of Webster's delay equation is used to approximate platoon effects. Outputs include cycle length, phase sequencing, splits, offsets, and band speed that maximize bandwidth in both directions. Advantages are flexibility to vary cycle length and bandwidth and consideration of multiphase operation under a variety of timing strategies. Disadvantages include lack of emissions or fuel consumption data.

- **PASSER III** - PASSER III computes cycle length, phase sequencing, and splits that minimize average delay per vehicle for a pre-timed interchange. PASSER III uses a deterministic, macroscopic time-scan optimization model. It can also determine splits and offsets for interchange signals along a frontage road, but in this case bandwidth is the performance objective.

- **SIGOP** - By using a macroscopic traffic flow model, SIGOP determines cycle length, splits, and offsets of signals in a grid network that minimize delay. SIGOP can handle up to 150 intersections. Outputs include time-space plots along selected arterials and link statistics. Up to four phases can be modeled in SIGOP.

- **MOTION**- MOTION (Method for the Optimization of Traffic Signals in Online controlled Networks) is a prototype system for the automatic control of traffic lights under the global goal of optimized flow conditions and waiting times in a network. The first field implementation took place in Cologne, Germany in 1995 and its basic methodology was developed in the ATT/DRIVE II project. The basic idea is to combine the advantages of well-designed 'Green Waves' for major traffic streams in a network with the flexibility of an immediate response of local signals to the actual state of traffic. MOTION determines a network cycle time, mainly according to the traffic volumes at critical intersections. Based on the current average turning movements at intersections, a number of alternative basic signal programs are then calculated. In the second step the O-D pattern and corresponding traffic streams through the network are determined. They create, with external preconditions, the network optimization plan. Another feature of the system is that it gives special priority to public transportation vehicles.

Adaptive Control Strategies

As opposed to the models outlined above, which use historical data to create one or more optimized timing plans, adaptive control strategies use real time data from detectors to perform constant optimizations on the signal timing plan for an arterial or a network. This means that signals can adapt to non-recurring congestion, incidents, events, or traffic demand growth over time, without needing to be reset.

- **UTCS Control Strategies** – As mentioned above, the second and third generation control strategies developed by the FHWA are adaptive control strategies:

Second Generation Control (2-GC) - 2-GC control uses an online strategy that implements signal timing plans based on real time surveillance data and predicted values. The optimization process can be repeated every five minutes. However, to avoid transition disturbances, new timing plans cannot be implemented more than once every 10 minutes. The software also contains a traffic prediction model, CIC, and a transition model to minimize transition time between two plans.

Third Generation Control (3-GC) – Similar to 2-GC, 3-GC is a fully responsive, online traffic control system. Similar to 2-GC, it computes control plans to minimize a network wide objective using predicted traffic conditions. It differs from the 2-GC model in that the period after which timing plans are revised is shortened to 3 to 5 minutes, and the cycle lengths are

allowed to vary among the signals during the control period.

Table 1 Comparison of UTCS Control Strategies

FEATURE	First Generation Control (1-GC)	Second Generation Control (2-GC)	Third Generation control (3-GC)
Update interval	15 min	5-10 min	3-5 min
Control plan generation	Off line optimization selection from a library by time of day, traffic responsive, or manual mode.	Online optimization	Online optimization
Traffic prediction	None	Historically based	Smoothed current values
Cycle length determination	Fixed within each section	Fixed within variable groups of intersections	Variable in time and space. Predetermined for control period.

Source: Gartner, Nathan, Chronis Stamatindius, and Phillip Tarnoff. Development of Advanced Traffic Signal Control Strategies for ITS. Transportation Research Record 1494, 1996.

- **Distributed Intelligence Traffic Control System (DITCS)** - DITCS is a control system in which intersection controllers use timing plans but can dynamically adjust the splits to suit traffic conditions at the controller level. DITCS are closed loop systems providing real-time traffic adaptive control. The central system sends synchronization pulses, but most functions are performed at the intersection level maximizing the use of computing power. Some well known DITCS are Sydney Coordinated Traffic Adaptive System (SCATS) and TracoNet, described below:

- **SCATS** - Developed by the New South Wales Department of Main Roads, SCATS is a dynamic control system with a decentralized architecture. SCATS updates intersection cycle length using the detectors at the stop line. SCATS allows for phase skipping. Offsets between adjacent intersections are predetermined and adjusted with the cycle time and progression speed factors.

- TracoNet- TracoNet is a distributed intelligence closed loop network control system used for coordinating, controlling and facilitating the flow of vehicular traffic. It can operate in all control modes, including fully actuated. Traffic responsive algorithms based on pattern matching are also available.

- **Split Cycle and Offset Optimization Technique (SCOOT)**- SCOOT is an off-the-shelf centralized computerized traffic control model developed at the Transportation Road Research

Laboratory in the U.K. It is an enhancement over first generation UTCS systems and provides real-time adaptive control. SCOOT uses system detectors to measure traffic flow profiles in real time, and along with predetermined travel times and the degree of saturation (the ratio of flow-to-capacity), predicts queues at intersections. Adjustments of cycle length, phase splits and offsets are made in small steps to operate at a preset degree of saturation (usually 90%). Tests have shown that SCOOT is most effective when demand approaches, but is less than, capacity, where demand is unpredictable, and when distances between intersections are short. Traffic control systems using SCOOT are prevalent in Australia, Asia, and recently in North America. The three key principles of the SCOOT system that make it different from the TRANSYT model are:

- it measures the cyclic flow profile in real time as opposed to deriving it from upstream turning movements

- it updates an online model of queues continuously as opposed to only updating once

- it makes incremental as opposed to global optimizations to the signal settings

- The SCOOT and SCATS traffic models are built on a vertical queue model and thus can not consider the effect of downstream link congestion on the signal output. These models operate fairly well as long as the network is not overly congested. However, they fail to model the effect of downstream congestion on the capacity of upstream intersections during queue spillback. The queuing model is updated from queue measurements from the field.

•□□□□□□□ **Real-time Traffic Adaptive Signal Control System (RT-TRACS)** - In 1991 the FHWA solicited proposals for the development of a real-time, traffic adaptive signal control system called RT-TRACS. Shortly thereafter, the FHWA contracted with PB Farradyne to develop and implement RT-TRACS. The RT-TRACS control logic assesses the current status of the network with forecasting capabilities, allowing proactive, not reactive, response. The most fundamental requirement of this system is to effectively manage and respond to rapid variations in traffic conditions. RT-TRACS consists of a number of real-time control prototypes that each function optimally under different traffic and geometric conditions. When conditions dictate, RT-TRACS can automatically switch to another strategy. The FHWA realizes that this control logic must be integrated with freeway performance data and provide network wide control. A thorough understanding of past experience with advanced traffic signal control strategies is critical to the development of effective RT-TRACS strategies for ITS. Features of the RT-TRACS design include:

- both distributed and centralized traffic control;
- dynamic priority control on selected routes;
- capability to interact with dynamic traffic assignment to implement proactive control;
- improved fallback capabilities in case of surveillance system failure;
- effective use of the accumulated experience with real-time control.

Five prototypes strategies are currently being developed and evaluated for use in the RT-TRACS program. The FHWA awarded five separate contracts to develop these real-time prototype strategies. The contracts were awarded to the University of Arizona, the University of Minnesota, the University of Massachusetts (Lowell)/ PB Farradyne, Wright State University in Ohio, and the University of Maryland/University of Pittsburgh. Kaman Sciences Corporation is responsible for evaluating these prototypes using the CORSIM simulation model. In late 1997, the FHWA and the University of Arizona teamed to develop and field test one of these prototypes, RHODES, an open architecture version of RT-TRACS that will utilize an alternative database management system and NTCIP protocol.

Three of these prototypes, the **RHODES** prototype from the University of Arizona, **OPAC** (Optimization Policies for Adaptive Control) from PB Farradyne/ University of Massachusetts (Lowell), and **RTACL** from the University of Pittsburgh/University of Maryland, are at an advanced state of development. Initial simulation testing showed that these prototype strategies produced statistically significant improvements in traffic throughput and reduced average delay. The results of the laboratory evaluation of the RHODES

prototype have indicated a reduction in delay, stops, and fuel consumption of 24 percent, 9 percent, and 6 percent, respectively, while maintaining the same throughput as the baseline case (vehicle actuated control). A 16-intersection arterial in Reston, Virginia has been selected for the field implementation. Instrumentation of the arterial is in progress. Further testing is expected to occur in Seattle, Washington, and Chicago, Illinois.

ATSAC (Automated Traffic Surveillance and Control) -- The city of Los Angeles created ATSAC --based originally on UTCS-- one of the earliest and most extensive advanced traffic management systems, including centralized, adaptive traffic signal control. The system includes surveillance via loop detectors and closed circuit television, signal optimization software, and real-time remote control of signals.[14] Please see the case study below.

Table 2: Comparison of Traffic Control Systems

Operations	**UTCS**	**SCOOT**	**SCATS**	**TracoNet**
Control	Central	Central	Distributed	Distributed
Offsets	Pre-determined	Dynamic	Pre-determined	Predetermined
Traffic Responsive	plan matching using system detectors	traffic projection algorithms using system detectors	split adjustment for existing traffic using occupancy detectors	Pattern matching using system detectors
Cost of software and master ($1994)	$100,000	$350,000	$130,000	$8,000
Contact	Honeywell, Sperry, etc.	TRRL, GE, Fortran Systems	New South Wales Dept. of Roads, Phillips, AWA	Traconex

Source: Kagolanu, K. A Comparative Study of Traffic Control Systems. Institute of Transportation Engineers 1994 Compendium of Technical Papers.

Standard Traffic Controllers

Standard traffic controllers are the field hardware used in signalized intersection control. It is important to consider the capability of existing traffic controllers when implementing a new traffic signal control strategy, as earlier models may not be able to process the amount of data required.

- **NEMA TS-1**- The first broadly accepted industry defined traffic controller, NEMA TS-1 is based on conformance to standard mechanical and electrical connectors. The architecture is closed to the customer, which does not allow a DOT to change the software / hardware and functionality of the product.
- **Caltrans 170**- Created by Caltrans in the 1970s, this controller defined not only the interface standard, but also the microprocessor to be used and its memory map. This approach allowed independent software developers to create products, and DOTs benefited from multiple hardware and software vendors. However, they are now becoming outdated because they are not able to support today's standards.
- **NEMA TS-2-** Recognizing the need for a new controller, NEMA published the TS-2 specification in 1992. The system utilizes a serial I/O architecture to provide modularity and expandability for the I/O detectors. The TS-2 architecture remains closed to the integrator, so the inherent limitations of a closed system remain. Although the specifications have been out since 1992, many believe that the Caltrans

2070 specification will preclude widespread adoption of NEMA TS-2.

- **Caltrans 2070-** The Caltrans Model 2070 ATC traffic controller is a new and advanced controller intended to satisfy the high-end needs of the advanced freeway and urban control systems and those applications requiring greater performance and/or flexibility than is currently available with the Model 170/E traffic controllers. Specifications for the Model 2070 controller are currently being refined.

ASSESSMENT

Key Results

Traffic signal control can provide significant benefits for traffic flow on a surface street network. However, it seems that the most advanced systems are not always the most effective. Careful attention must be paid to implement a traffic signal control system that is appropriate and cost-effective for the area. In addition, it is important to assess the current state of the existing traffic signal control system when projecting results of an improvement to the system. If a system is currently pretimed, and ACS is installed, there will probably be a significant improvement. However, if the current system is already fairly updated, the improvements will generally not be as great.

Surprisingly, extensive field tests in the 1980s, which compared each generation of UTCS on an arterial and a grid network to a standard, pre-timed system, showed that the simpler methods performed better on average (See Table 3). 1-GC, in its various modes of operation, performed best overall, and demonstrated that it can provide measurable reductions in total travel time over that which could be attained with a well maintained fixed time system. In 2-GC and 3-GC, the effectiveness of the control system response depends entirely on the quality of the prediction model. The traffic responsive plan selection method was generally better than the time of day method. The results of the 2-GC method were mixed, but overall inferior to the 1-GC. The 3-GC strategy was unsuccessful in responding to traffic flows and degraded performance under almost all traffic conditions. Counter-intuitively, the more responsive strategies resulted in poorer performance than fixed cycle, non-responsive strategies. A close examination of the experiments reveals that expectations were not fulfilled because the models and procedures used in the UTCS study failed. Proposed reasons for the limited success of adaptive control included:

- Inherent inaccuracies in the measurement prediction cycle, such that the strategies could not respond fast enough.

- The frequent transition in signal timing may incur considerable delays.

- Insufficient time allocated for models to calculate a good optimum.

Table 3 presents a summary of some extensive field tests conducted on UTCS control systems in the United States in the early 1980's, comparing each generation on an arterial

and grid network. The UTCS strategies are compared to operation with standard pre-timed traffic control. (+ indicates an increase in the travel time)

Table 3 Comparison of Results of UTCS Strategies

	% Change in aggregate veh-minutes of travel with respect to base			
UTCS Strategy	**AM Peak**	**Off Peak**	**PM Peak**	**Daily Average**
1-GC (Arterial)	-2.6	-4.0	-12.2	NA
1-GC (Network)	-3.2	+1.9	-1.6	NA
2-GC (Arterial)	-1.3	-3.8	+0.5	-2.1
2-GC (Network)	+4.4	+1.9	+10.7	+5.2
3-GC (Arterial)	+9.2	+24.0	+21	+16.9
3-GC (Network)	+14.1	-0.5	+7.0	+8.2

Source: Gartner, Nathan, Chronis Stamatindius, and Phillip Tarnoff. Development of Advanced Traffic Signal Control Strategies for ITS. Transportation Research Record 1494, 1996.
NA: Data not available

Benefits

Traffic signal control improvements are very effective at reducing congestion. In fact, they generally provide the greatest payoff compared with any other method for reducing congestion on surface streets. [12] Traffic signals do not need to become "state-of-the-art" in order to realize great improvements in traffic flow. Often, one simple improvement, such as interconnecting signals that were previously operating independently, can produce significant results. According to [12], projects in the United States have found that:

- Interconnecting previously uncoordinated signals or pretimed signals, and providing newly optimized timing plans and a central master control system can result in a travel time reduction of 10-20 percent.
- Installing advanced computer control has resulted in about a 20 percent travel time reduction when compared to interconnected pretimed signals using old timing plans.
- Installing advanced computer control has resulted in a 10-16 percent travel

time reduction when compared to non-interconnected, traffic actuated controls.

- Installing advanced computer control, when compared to interconnected pre-timed control with relatively active signal timing management, has resulted in an 8-10 percent travel time reduction.
- Optimizing traffic signal timing plans, when compared to previously interconnected signals with various master control forms and varying previous signal timing qualities, has resulted in a 10-15 percent reduction in travel time.

In addition to significantly reducing travel time, traffic signal control improvements also reduce stops, fuel consumption, and emissions. For example, the Texas Traffic Light Synchronization Grant Program II (TLS II) achieved reduced fuel consumption, delay and stops by 13.5 % (20.8 million gallons/year), 29.6% (22 million hours/year), and 11.5% (729 million stops/year), respectively. The total savings to the public in the form of reduced fuel, delay, and stops was approximately $252 million in the following year alone. More significantly, however, the study indicated that an average of 10 gallons of fuel was saved for every dollar that was spent on the retiming project [8].

An aggressive signal retiming effort in California resulted in a benefit-cost ratio of 58 to 1. The program improved 3,172 signals across the state, resulting in a 15% reduction in delay, 16% reduction in stops, and a 7.2% reduction in travel time throughout the system. The money saved from reduced fuel consumption (8.6%) alone returned the total cost of the program 18 times over. [12]

Adaptive Control Strategies (ACS) have additional benefits, such as increased safety. ACS can reduce the number of stops through improved signal coordination, which in turn reduces the chance of rear-end collisions. In comparison to fully optimized fixed-time systems, SCATS has been shown to reduce stops by up to 40 percent [11]. Since implementing SCATS, Broward County, Florida has seen a 28 percent decrease in stops, and Oakland County, Michigan showed a 33 percent reduction in stops. ATSAC in Los Angeles has reduced stops by 41 percent [11].

In addition, ACS have the added advantage of being able to grow with a community. The ITS deployment tracking database shows that few areas re-time their signals each year. In fact, ITE estimates that nearly 75 percent of all signals in the United States need to be re-timed [11]. Most metropolitan areas do not have the resources to re-time their signals regularly. However, with ACS there is no need to reset signals, because the system continually generates new timing plans. This is especially beneficial to areas of high growth, where even the best fixed timing plans quickly become out-of-date.

Costs

Traffic signal control improvements vary widely in cost, and can be quite expensive. Table 4 shows typical costs associated with traffic signal improvements, and Table 5 shows estimated costs of ACS components.

Table 4 Costs of Traffic Signal Improvements

Equipment or software updating	$2000-$3000 per signal
Timing plan improvements	$300-$400 per signal
Signal coordination and inter-connection	$5000-$13000 per signal
Signal Removal	$300-$400 per signal

Source: Environmental Protection Agency, 1991

Table 5 Estimated Costs of ACS Components

System	Central Hardware ($)	Central Software ($)	Local Controllers ($)*	Detectors ($)*
SCATS**	30,000	40,000-70,000	4,000-6,000	5,000-7,000
SCOOT	30,000	NA	NA	5,000-7,000
OPAC	20,000-50,000	100,000-200,000	4,000-6,000	NA
RHODES	50,000	500	NA	NA
ATSAC	40,000-50,000	1,000 + license	8,000-10,000	5,000-10,000

Source: What Have We Learned about Intelligent Transportation Systems?, 2000

*per intersection **requires regional hardware

In addition to the initial cost, signal operations and maintenance costs can be significant, and must be considered carefully. Several categories of maintenance should be considered [12]:

- Preventative Maintenance, to be performed at regular intervals to avoid unnecessary problems
- Response Maintenance, which includes quick response to emergency situations as well as trouble-shooting
- Design Modification, which deals with the need to monitor new equipment and new signal locations in order to ensure safe and effective operation

ACS, when compared to standard traffic control devices, can reduce operations and maintenance costs, since the cost of maintenance for an ACS system is much lower than the cost of retiming. However, it is not that simple, because while signal retiming costs decrease, other costs, such as loop maintenance increase. [11]

and Maintenance Costs for SCOOT Compared to Standard Traffic Control Devices

Equipment/Task	Costs of SCOOT vs. Standard
Controllers	Same
Detectors	Increases
Signal Plans/Updates	Decreases

Source: What have we learned about Intelligent Transportation Systems? 2000

Implementation Challenges

The most common challenge to implementation of traffic signal control improvements is initial financial cost. Luckily, as has been seen in California and Texas, the benefits from a well-designed improvement program far outweigh the initial cost.

It is crucial to use pilot studies and other evaluation techniques in selecting a system that will work well for a particular area. Some systems may not improve congestion in a certain area at all. For example, a limited SCOOT installation in Anaheim, California, produced little improvement, and even increased delay in some cases. According to a US Department of Transportation-sponsored evaluation of the system, detector placement may have been the cause of the sub-optimal performance. [11]. In addition, in areas with fairly predictable traffic demand and low growth, a well-maintained fixed-time/time-of-day signal may perform just as well as ACS.

The increased complexity of new traffic signal control systems may also be an impediment.

Additional training is normally required for ACS systems, which are not considered user-friendly. Furthermore, ACS is highly dependent on the communications network and the traffic detectors. The system cannot work efficiently without these reliable inputs.

WHERE IS TRAFFIC SIGNAL CONTROL IMPLEMENTED?

Case Studies

Los Angeles, CA

Automated Traffic Surveillance and Control (ATSAC)
With its large population and its auto-dependent urban form, Los Angeles experiences extremely heavy congestion on its arterials. The situation is exacerbated by activity centers, such as the coliseum and the airport, which create large and less predictable surges of traffic. In response to this problem, the city of Los Angeles created ATSAC, one of the earliest and most extensive advanced traffic management systems, including centralized, adaptive traffic signal control. The system, first utilized around the Coliseum for the 1984 Olympic Games, was initially based on the FHWA's UTCS signal control software, and customized by a consulting firm, JHK & Associates. The system includes surveillance via loop detectors and closed circuit television, signal optimization software, and real-time remote control of signals.[14]

ATSAC has had tremendous success in reducing system-wide congestion, as well as in clearing event traffic. Since the system was implemented, coliseum traffic clears within an hour after a big concert, compared with over two hours previously. [14] In addition, the system has been found to reduce stops by 35%, intersection delay by 20%, travel time by

13%, fuel consumption by 12.5%, and air emissions by 10%. The benefit/cost ratio was found to be 9.8:1, and the system paid for itself in less than one year. [15]

Oakland County, Michigan

Faster and Safer Travel through Traffic Routing and Advanced Controls (Fast-Trac)
About ten years ago, residential population and economic activity skyrocketed in Oakland County, Michigan. Unfortunately, along with the benefits of this growth came significant traffic congestion. The cost of solving the congestion problem was estimated to be almost $1 billion. Instead of resorting to road and highway expansions, Oakland County looked for a more innovative approach. The result was the Faster and Safer Travel through Traffic Routing and Advanced Controls (Fast-Trac) system.

Fast-Trac integrates advanced traffic management with advanced traveler information systems, with the SCATS adaptive control strategy at the core. With their SCATS system, Oakland County can claim many "firsts": the first adaptive traffic control system in the U.S., the first SCATS application in the western hemisphere, and the first to use video image processing with SCATS. Oakland County chose to use video surveillance instead of loop detectors with SCATS for several reasons. Video cameras can be installed on any surface and in any weather conditions-- a very important advantage in the Michigan climate. Also, one video camera can monitor several lanes of traffic, while a conventional loop detector can only monitor one.

Fast-Trac has been very successful on several fronts. There has been an 89-percent drop in the number of accidents at the most dangerous intersections, a 100 percent decrease in the number of serious injuries at those same intersections, and 40-plus hours a year trimmed from the average commute time.[16]

At the World Cup soccer matches held in Detroit's Silverdome--and since then, at other major concerts and special events--tests showed that the traffic management system eased traffic flow and reduced the need for police to manually direct traffic. Overall, the program is responsible for a 19 percent increase in rush-hour travel speed and a significant decrease in accidents. Studies suggest that Fast-Trac could potentially reduce the average number of vehicle stops by one-third, decreasing the incidence of rear-end collisions and reducing carbon monoxide emissions by 12 percent. [17]

Anaheim, California

Field Operational Test with SCOOT
Anaheim, best known for Disneyland, also houses many other large event centers, including a convention center; a professional baseball stadium, Anaheim Stadium; and a professional hockey ice rink, Arrowhead Pond. These event centers have a collective maximum attendance of 200,000 people; when combined with Anaheim's 300,000 residents, major traffic congestion results. With these unpredictable surges of event traffic, it seemed that Anaheim was a perfect candidate for an ACS implementation.

As part of the federally funded Anaheim Advanced Traffic Control System Field Operations Test (FOT), a version 3.1 SCOOT system was installed by Siemens for a portion of the City of Anaheim network near Arrowhead Pond and Anaheim Stadium. From fall 1994 to spring 1998, PATH researchers conducted a study comparing SCOOT to the previous UTCS system, which was already considered state-of-the-art.

Contrary to expectations, SCOOT was not found to be an improvement over the UTCS system. The SCOOT system produced lower intersection delays in some cases, but more often it produced higher delays. In cases where there was improvement, the improvement was less than 5%, and in cases where conditions worsened, the increase in delay was less than 10%.

There were several problems that led to SCOOT's less-than-ideal performance. Among others,

SCOOT predicts traffic conditions using input from loop detectors located upstream of the intersection. The loop detectors in Anaheim were located closer than usual to the intersection, and therefore did not give SCOOT completely accurate information on current traffic conditions. Also, as a result of cumulative communication or other system faults, the SCOOT intersections were unexpectedly being isolated from SCOOT control. Such faults can be cleared manually in most cases, but this requires active intervention on the part of the TMC operator. If faults are actively cleared rather than being permitted to accumulate, the signals involved usually remain under SCOOT control. The number of signals slipping from SCOOT control decreased substantially once the evaluation team demonstrated to Anaheim TMC operators the need to clear faults as they occurred. Unfortunately, however, these conditions still resulted in substantial data loss for this portion of the evaluation.[18]

SCOOT's performance in Anaheim should not be taken as a failure on the part of the control strategy itself, but rather as a caution to potential ASC implementors, highlighting the importance of field tests and other preliminary research.

REFERENCES

[1] Computer Controlled Traffic Signal System, USDOT, Federal Highway Administration, 1982.

[2] Gartner, Nathan H., Stamatindius, Chronis, and Tarnoff, Philip, J., Development of Advanced Traffic Signal Control Strategies for Intelligent Transportation Systems: Multilevel Design, Transportation Research Record 1494, 1995.

[3] Dell'Olmo, Paolo, and Mirchandani, Pitu B., REALBAND: An Approach for Real-time Coordination of Traffic Flows on Networks, Transportation Research Record 1494, 1996.

[4] Busch, Fritz, MOTION – a new approach to urban network control, Traffic Technology International 1996.

[5] Genovese, Joseph, A., SCOOT in the USA, Institute of Transportation Engineers 1994 Compendium of Technical Papers.

[6] Rahka, H., and Aerde, M. Van, REALTRAN: An Off-line Emulator for Estimating the Effects of SCOOT, Transportation Research Record 1494, 1996.

[7] Grover, Albert, et. al., Multijurisdictional Traffic Signal Coordination - A Pleasant Experience !, Institute of Transportation Engineers 65th Annual Meeting, 1995 Compendium of Technical Papers.

[8] Fambro, Daniel, et. al., Benefits of the Texas Traffic Light Synchronization (TLS) Grant Program II, Texas Transportation Institute, 1995.

[9] Institution of Civil Engineers, Electronic Traffic Control, How Does UK Compare?, 1988.

[10] Transportation Infrastructure - Benefits of Traffic Control Signal Systems Are Not Being Fully Realized, US General Accounting Office, 1994.

[11] Hicks, Brandy and Carter, Mark, What Have We Learned About Intelligent Transportation Systems?--Arterial Management, US Department of Transportation/Federal Highway Administration, 2000.

[12] Meyer, Michael, A Toolbox for Alleviating Traffic Congestion and Enhancing Mobility, Institue of Transportation Engineers, 1997.

[13] Gordon, Robert, et al., Traffic Control Systems Handbook, US Department of Transportation, Federal Highway Administration, 1996.

[14] Dahlgren, Joy, et al., Lessons from Case Studies of Advanced Transportation and Information Systems, California PATH, 1996.

[15] Rowe, Edwin, The Los Angeles Automated Traffic Surveillance and Control (ATSAC) System, Los Angeles Department of Transportation, 1990.

[16] Gravat, Jack, FAST-TRAC - Success In Any Lane, http://www.itsdocs.fhwa.dot.gov/%5CJPODOCS%5CPRESSREL/$801!.PDF, undated.

[17] Traveling with Success: How Local Governments Use Intelligent Transportation Systems: On the Fast-Trac to Economic Health-- Oakland County, Michigan, Public Technologies, Inc., undated [http://pti.nw.dc.us/task_forces/transportation/docs/success/travel31.htm]

[18] Moore, Jayakrishnan, McNally, MacCarley, "SCOOT Performance in Anaheim Advanced Traffic Control System", Intellimotion - Research Updates in Intelligent Transportation Systems, Vol. 8, No. 3, 1999

Author: Rebecca Pearson, Last Update: 11/01/01