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# CHAPTER 3

## Traffic Signal Control Systems



Traffic-signal control systems coordinate individual traffic signals to achieve network-wide traffic operations objectives. These systems consist of intersection traffic signals, a communications network to tie them together, and a central computer or network of computers to manage the system. Coordination can be implemented through a number of techniques including time-base and hardwired interconnection methods. Coordination of traffic signals across agencies requires the development of data sharing and traffic signal control agreements. Therefore, a critical institutional component of Traffic Signal Control is the establishment of formal or informal arrangements to share traffic control information as well as actual control of traffic signal operation across jurisdictions.

Signal coordination systems are installed to provide *access*. A traffic-signal system has no other purpose than to deliver favorable signal timings to motorists. The system provides features that improve the traffic engineer's ability to achieve this goal. These are primarily *access* features. They provide access to the intersection signal controller for maintenance and operations. The more complete and convenient the access, the more efficient the operator will be and the more effective the system.

In addition to control of traffic signals, modern systems also provide wide-ranging surveillance capabilities, including various kinds of traffic detection and video surveillance. They also provide more powerful traffic-control algorithms, including the potential for adaptive control and predictive surveillance.

#### SOURCES:

- *Traffic Control Systems Handbook*, February 1996, Publication No. FHWA-SA-95-032, Federal Highway Administration.
- *Manual on Uniform Traffic Control Devices for Streets and Highways*, Federal Highway Administration.
- *Improving Traffic Signal Operations, A Primer*, February 1996, Publication No. FHWA-SA-96-007.
- Computerized Traffic Signal Systems, Training Course, To be Published in 1997, NHI Training Course No. 13310.

## 3.1 SURFACE STREET CONTROL

Surface street control systems provide the majority of traffic-signal system applications. They are intended solely to provide control of networks of signal-controlled streets. When traffic-signal systems are integrated with freeway-management systems, their objectives take on a larger perspective. Integrated traffic-signal systems will be covered in a later section.

### 3.1.1 TECHNIQUES/STRATEGIES

#### Isolated Signals

Isolated traffic signals are the basic building blocks of signal systems. Traffic signals are installed when traffic at an intersection becomes too heavy for motorists to efficiently or safely assign their own right of way. Because a traffic signal removes the motorist's ability to coordinate his turn at an intersection, it is considered a more restrictive form of control than uncontrolled or stop-controlled intersections. For this reason, traffic signals are generally regarded as a last resort for intersection traffic control.

The decision to install a traffic signal depends on the conditions at the intersection meeting one of a series of warranting conditions, as defined in the Manual on Uniform Traffic Control Devices. These warranting conditions are intended to define the common circumstances when a signal might be appropriate. In spite of these specified warranting conditions, the decision to install a traffic signal must be made by a qualified traffic engineer based on a careful study of the intersection and potentially less-restrictive alternatives.

Briefly, the conditions generally thought to warrant traffic-signal operation follow.

**General Traffic Volumes** - When traffic volumes at most of the intersection approaches reach the point where other forms of control cannot efficiently assign right of way to the approaching motorists.

**Interruption of Continuous Traffic** - When traffic on a major street is so heavy that traffic on a lightly travelled side street has little opportunity to cross or enter the main-street traffic. This condition requires heavier traffic on the main street than the previous condition, but allows lighter traffic on the side street.

**Pedestrian Volumes** - When pedestrian traffic is heavy enough to justify the interruption of vehicular traffic.

**School Crossings** - If judged necessary by the traffic engineer, a traffic signal may be used to facilitate the crossing of school children.

**Progressive Movement** - Sometimes a traffic signal will help keep platoons of cars tightly formed to enhance the coordinated flow along a street and encourage an appropriate speed.

**Accidents** - Traffic signals are sometimes effective in reducing accidents that result from the inability of motorists to safely assign their own right of way. These accidents typically involve right-angle collisions.

**Some Combination of the Above** - A collection of conditions that generally comprise some of the above conditions, or when streets that are clearly major elements of a transportation network intersect.

Once a traffic signal is installed, it may be operated one of two ways: pretimed or actuated. In practice, the installation of isolated pretimed intersections has become rare. Most signals in isolated circumstances control highly variable traffic, and therefore work better when actuated by traffic.

- a. *Pretimed Operation*. In this form of operation, the red, yellow, and green indications are timed at fixed intervals. Pretimed operation assumes that the traffic patterns can be predicted accurately

based on time of day. As previously mentioned, this predictability can usually only be achieved by controlling the traffic entering the intersection with upstream signals, as in a system. In isolated locations, however, the traffic approaching the intersection arrives randomly, and is not usually predictable enough to make pretimed operation a good choice. But pretimed operation does not require traffic detectors at the intersection, and is therefore much cheaper to install. Consequently, pretimed operation is usually used at isolated intersections only when funds do not allow actuated operation.

- b. *Actuated Operation.* Intersections with this form of control consist of actuated traffic controllers and vehicle detectors placed in or on the roadways approaching the intersection. In actuated operation, the control algorithm is primarily concerned with when green intervals terminate. With actuated controllers, green intervals may terminate in one of four ways:
1. *Maximum Green Time is Reached.* Usually called *maxing out* or *timing out*, this occurs when a user-determined maximum green time is reached. The interval is terminated and the next interval in the sequence is allowed to time.
  2. *Traffic Flow Ceases on the Approach.* When a gap in traffic appears that is greater than a user-determined threshold, the controller will terminate the green interval in favor of other movements that have demand. This form of termination is known as *gapping out*.
  3. *A Signal System Forces the Termination.* When an actuated signal is part of a coordinated system, the system keeps the signal in step with the intended operation by forcing green intervals off at the intended times in the signal cycle. This is called applying a *force-off*.
  4. *The Signal is Preempted.* As discussed below, when a priority vehicle approaches the intersection, nonpriority green intervals may be terminated in favor of the priority movement.

In most cases, only the first two of these termination methods will be used at isolated locations. Forcing is reserved for coordinated operation, and preemption is a special case.

During actuated operation, a traffic movement will be served with a green indication. This green interval will last a user-defined minimum amount of time. As long as cars continue to cross the approach detectors frequently enough, the green interval will be extended. These extensions will continue until the cars thin out sufficiently to allow the signal to gap out, or until the interval reaches the maximum time.

At isolated intersections, actuated operation considers only when to terminate the current traffic movements being served. Actuated controllers do not determine whether extending the green for that movement will meet intersection-wide objectives for traffic operation, such as minimizing delay. Consequently, the objective function of normal actuated extension is to minimize unused green time. A corollary of this objective is to maximize green time that is fully utilized. At actuated signals, therefore, effective cycle lengths tend to grow uncontrollably as traffic demand nears capacity. Without signal coordination, the maximum green times are the only mechanism in the controller to impose some discipline on the cycle length. At critical intersections, good practice would dictate that maximum green times are calculated to provide effective operation under capacity-flow conditions. These conditions vary depending on time of day, and most controllers are therefore equipped with two or more sets of maximum green times to be used at different times of day.

## Interconnected Signals

### a. *Distributed Systems*

Distributed systems are those in which, generally, the intersection controller is responsible for control decisions at the intersection. Distributed systems come in many varieties, ranging from small closed-loop systems (see below) to powerful large-scale systems.

When traffic signals are located close enough together that traffic remains in recognizable platoons from one intersection to the next, traffic engineers will usually seek to coordinate their operation. Signal coordination merely requires that the signal timings at multiple intersections be timed to meet network-wide objectives for traffic flow. This usually requires all signals to operate at the same or a compatible cycle length, with careful design of the time-space relationships between the intersections. The signals, therefore, need some means of staying in step with each other.

At the most basic level, each intersection's traffic signal may contain an accurate clock, with all intersections coordinated according to their internal clocks. As long as the clocks at the intersections remain synchronized with each other, the signals stay in proper coordination. This form of coordination is known as *time-base coordination*. Time-base coordination is used when a communications infrastructure is unavailable.

When a communications infrastructure can be constructed, signals can be coordinated more effectively than with time-base operation.

The differences between distributed systems and centrally controlled systems have blurred in recent years. Most modern centralized systems have many of the important features of distributed systems, and most distributed systems offer many of the most useful central control features.

Distributed systems have the following characteristics:

- They rely on powerful local-intersection controllers. Because the power of the system is inherent in the local controller, these controllers must have all the features desired for signal control at the intersection. Most local-intersection controllers available have sufficient power to operate effectively in a distributed system. Some of the newest systems, however, use leading-edge controllers, such as the Model 2070, which does have a cost impact on the system.
- They are inherently robust. Distributed systems do not transmit mandatory real-time control commands over the communications network. Consequently, the intended operation of the system can be maintained even during communications and central computer downtime. True distributed systems incorporate this characteristic more effectively than centralized systems with a time-base backup. They are always operating in time-base coordination, with the central computer and communications network used only to maintain the accuracy of the internal clock. When a failure occurs, they do not have to transition to backup operation; they are already there.
- They are easily expanded. Each time a new intersection is built, the computing capacity of the system, which includes the local controllers, is expanded sufficiently to incorporate the new intersection. All that must be added is communications infrastructure.

- They are often inexpensive. The communications network need not be reliable enough to carry mandatory real-time communications. Consequently, inexpensive communications alternatives, including wireless alternatives, are viable options that can significantly reduce the cost of a new system. The savings in communications infrastructure usually compensates for the potential higher cost of local controllers. Distributed systems typically cost between \$10,000 and \$30,000 per intersection.
- They often do not provide real-time surveillance. Distributed systems do not need real-time polling of intersections for control purposes, and some systems are installed on communications plants that do not allow real-time polling. In these cases, real-time surveillance also cannot be provided.
- They do not provide for centralized adaptive-control algorithms. Some adaptive-control algorithms use a centralized optimization facility that requires centralized control. SCOOT (Split, Cycle, Offset Optimization Technique) is an example of this type of system. Such operation is not possible on distributed systems that cannot provide reliable real-time control communications.
- The central processor in the distributed system is limited primarily to operator interface and display functions.

#### When To Use Distributed Architectures

Distributed systems may be preferred when:

- Powerful local intersection control is desired.
- Project budgets limit the installation of new linear infrastructure and fault-tolerant central computer networks.
- Improved reliability is required through the use of microprocessors and multiple levels of fall-back control.
- Existing infrastructures must be used.
- The signal system has few existing facilities (e.g., computers, interconnect).
- Wireless communications technologies must be used.
- Absolute real-time surveillance is not needed.
- Centrally optimized adaptive control is not needed.

#### b. *Central Control Systems*

In centralized systems, a central computer makes control decisions and directs the actions of individual controllers. Each intersection requires only a standard controller and interfacing unit and does not perform any software functions.

Central systems have the following characteristics:

- They depend on reliable communications networks. Because real-time control commands are transmitted from the central computer to the local intersection, any interruption in the communications network forces the local controller to operate without that real-time control and revert to its backup plan. In traditional centralized systems, the backup operation was usually isolated traffic actuation. More recent systems revert to time-based coordination, but this still requires a transition from central control to local control. During this transition, signal coordination is usually lost for a short period of time. For this reason, communications networks for centralized systems usually include some form of fixed communications, with most agencies preferring to own their infrastructures. These communications media include twisted-pair copper wire and fiber-optic cable. The physical media typically provide inherent reliability of 99.995 percent to 99.99995 percent, with downtime ranging from a few seconds to a few minutes a year. In real systems, downtime is much higher because of physical intrusion on the infrastructure, though some fiber network approaches even minimize the effects of that danger.
- They depend on reliable central computers. Without the central computers, centrally controlled systems do not make much sense. When the central computer is down the system has the same problems as when the communications network is down, except that the problem affects all intersections, not just the few on that communications branch. Traditional centralized systems ignored this problem, and consequently earned a reputation for reliability problems. Newer centralized systems are employing advanced computer reliability techniques. The most interesting (and expensive) of these approaches is known as *fault tolerance*. Fault-tolerant systems employ two identical central computers networked together with a high-speed network connection. They both contain the same software, and share a joint operating system. Each computer runs in lock-step with the other, so that they operate as twins. When one computer fails the system is operated by the other computer, and the joint operating system arbitrates between the two systems during the onset of failure.
- They are often not easily expanded. Many traditional centralized systems are designed around a maximum network size. Increasing the size of the network requires a significant investment in central computer upgrades and often, upgrades in the software as well.
- They are expensive. Communications networks typically consume at least two-thirds of the cost of a system. Centralized systems require communications networks with high throughput reliability, which typically precludes the successful use of wireless communications. Consequently, the system costs include installation of a linear communications infrastructure. Centrally controlled systems usually cost between \$40,000 and \$80,000 per intersection.
- They provide excellent surveillance response time. The system's communications network is reliable enough to allow mandatory real-time control communications. In most situations, this requirement ensures once-per-second return of surveillance information.

- They allow centralized control algorithms. This is the one area where centrally controlled systems have a distinct disadvantage over distributed systems. Some control algorithms, such as SCOOT, require a central computer to calculate the optimization algorithm for the entire network. Only a centrally controlled system can provide this capability.

### When To Use Centralized Architectures

Centralized systems can be considered when:

- The budget allows linear communications infrastructure to each field device, in addition to the use of fault-tolerant central computer networks.
- Centrally optimized adaptive-control technologies are desired.
- The system will share resources, particularly communications and computer networks, with other systems that require high reliability, such as emergency-management systems.

### Network Architectures

#### a. *Centralized Architecture*

A centralized architecture is representative of the central control system in which a single central computer configuration directly controls the duration of every controller phase. The computer transmits commands that are used to terminate the existing phase to the controller. These commands are usually transmitted at a once-per-second rate.

#### b. *Distributed Architecture With Local Masters*

This architecture is representative of most closed-loop systems in which second-by-second commands are transmitted from local masters to the intersection controllers. The masters communicate with the central processor only when failure occurs, or when commanded to do so by the central processor. The connection between the masters and local controllers is usually made via dedicated twisted-pair cable. The connection between the masters and the central computer is usually made via dial-up telephone. In this way, it is possible to minimize the cost between remote groups of intersections and a central site. For this reason, closed-loop systems are popular with State and county agencies responsible for control of intersections dispersed over a wide geographic area.

#### c. *Distributed Architecture Without Local Masters*

This architecture is similar to the centralized architecture. However, its lower communication capacity requirements (i.e., sampling rate of once per minute or less) offers the ability to connect more than 100 intersections to a single voice grade facility. It is therefore practical to use a variety of alternative communications media such as radio or cable television. This architecture relies on the local controllers or communications interface devices to provide the local timing.

### Special Controls

#### Preemption/Priority Systems

Preemption systems started out as special hardware devices installed in controller cabinets to respond to special conditions. When those conditions appeared, the device would preempt the operation of the controller, and take over operation during the special condition. Most modern signal controllers have preemption capabilities built in, and therefore allow much greater flexibility in how preemption scenarios are operated.

Priority systems came about later, and provide the capability to give special consideration to one class of vehicles without completely preempting the normal operation of the signal.

The special conditions that call for preemption and priority are usually grouped into three categories: railroad, emergency vehicle, and transit vehicle events.

- a. *Railroad Preemption.* When traffic signals are placed close enough to a railroad grade crossing that conflicting signals cause a safety problem, a preemption capability is installed to take over operation of the signal while a train is near the crossing. At such a signal, the controller will either invoke flashing operation or a special preemption plan while the train is approaching or in the crossing. The special preemption plan usually starts with a track clearance interval, which allows cars that may be queued in the crossing to clear the tracks, and is followed by limited service, where the conflicting movements are red while the train is present, and nonconflicting movements are allowed to cycle.

In most controllers, railroad preemption takes the signal out of coordinated operation.

Controllers sense that trains are nearby by receiving a contact closure on signal lines tied into the grade crossing equipment.

- b. *Emergency Vehicle Preemption.* Many older systems were designed to provide continuous green signals along fixed emergency vehicle corridors. These corridors typically include the streets adjacent to fire stations, and these systems were often called *fire routes*. Fire routes are usually operated by a switch in the fire station that is manually operated by the firemen. The fire route stays in effect until the switch is turned off, or for a specified period of time. These approaches are best suited to centrally controlled systems, where the actions of the local intersections are being directed by a central computer. The fire route switch is then connected only to the central computer.

More modern emergency vehicle preemption schemes are intersection-based, and use special detectors at the signal to receive coded signals from emergency vehicles. These systems preempt regular signals to allow a green signal in the direction needed by the approaching emergency vehicle. Ambulances, as well as fire trucks, can use these systems. Because these approaches are intersection-based, they are more suited to application within distributed systems. A preemption event at a centrally controlled intersection will usually be dropped by the system and picked up some time after the preemption event is over, which worsens the operational effect of the preemption.

- c. *Transit Vehicle Preemption and Priority.* Some systems employ priority schemes for transit vehicles. The objective is to maximize passenger capacity of the network by providing ridership-enhancing operational advantages to transit vehicles. When the transit vehicles are not buses, priority operation may improve safety by reducing the number of stops required by larger rail-based transit vehicles.

Some transit schemes use preemption, but the trend is toward priority schemes that work within the signal-coordination pattern instead of removing the signal operation from the pattern. For example, if a signal detects an approaching transit vehicle, it may be programmed to see if the green for that movement can be serviced early, or held for a longer time, without forcing an interruption in the normal operation. Often, the delay to the transit vehicle can at least be reduced by using these approaches.

### 3.1.2 TECHNOLOGIES

#### Mainframe and UTCS Type Systems

In 1997, FHWA began development of the Urban Traffic Control Systems (UTCS) project. The system was installed in Washington, DC, and was used to develop, test, and evaluate advanced traffic-control strategies. The system contained 512 vehicle detectors whose outputs were used to determine signal timing at 200 intersections. Extensive data processing, communications, and display capabilities were made available to support the traffic-control strategy research. Later research efforts produced Extended and Enhanced versions of the software package that implements these concepts.

Virtually all mainframe traffic-control systems in operation in the United States are based on one of two UTCS packages, originally supported and distributed by the FHWA. The Extended UTCS package, which uses a menu-type user interface, is considered by many to be the benchmark program against which features of competing programs are measured. The other package is the Enhanced package, originally developed by the FHWA to overcome shortcomings of the Extended package and to add additional features.

The enhanced UTCS package was completed and demonstrated in Birmingham, AL, in 1983. Versions of the Enhanced package have been installed in Los Angeles and San Diego, CA.

#### Closed-Loop Systems

The closed-loop system is a distributed processor traffic-control system with control logic distributed among three levels: the local controller, the on-street master, and the office computer. These systems provide two-way communication between the local controller(s) and the on-street master(s) and between the on-street master(s) and the central computer. Typically, the local controller receives information from field devices (e.g., system detectors). The master controller receives information (e.g., traffic and/or internal diagnostics) from the local controller. The central computer enables the system operator to monitor and control the system's operations.

One major disadvantage of the closed-loop system is inability to control intersections connected to different local area masters in a unified manner. This restriction precludes extensive reconfiguring of control area boundaries in response to differing traffic conditions.

Three control modes are typically found with most closed-loop systems: time of day, manual, and traffic responsive. With the time-of-day mode, the controller unit can automatically select and implement a prespecified traffic-signal timing plan and sequence (cycle/offset/split) based on the time of day, day of

week, and/or time of year. With the manual mode, the operator specifies the pattern number of the desired traffic-signal timing plan and sequence via the computer console. With the traffic-responsive mode, the computer automatically selects the predefined traffic-signal timing plan best suited to accommodate the current traffic flow conditions in the signal network. The pattern selection and implementation is accomplished through a traffic flow data matching technique executed every five minutes on the five-minute mark.

Two other control modes have been used by some closed-loop systems: the controller unit parameter mode and the critical intersection control mode.

The closed-loop system consists of six components:

- System detectors,
- Local control equipment,
- Controller-master communications,
- On-street master,
- Master-central communications, and
- Central computer.

a. *System Detectors*

System detectors are used to sense vehicle presence or pulse duration and derive information on vehicle volume, occupancy, speed, queue length, etc. The detector technology has been discussed previously. However, care must be taken in the placement of these detectors to ensure the measures desired are obtained. For example, some systems select each parameter separately. The cycle length could be determined by the highest detector output level from one group of detectors while the offset could be determined by a ration of detector output values from the same or a different group of detectors. The split could be determined by a ratio of output values from still another pair or group of detectors.

Other systems use various forms of pattern matching, whereby a combination of volume and occupancy values from each detector is associated with each eligible timing plan and an algorithm is used to find the best match. In general, detectors should not be located near major driveways, nor in areas where there is poor lane discipline or weaving sections. They should be placed far enough upstream from the intersection so that stopped queues normally do not extend over the detector, unless queue lengths are desired. Understanding and familiarity with the traffic responsive algorithm is a prerequisite in detector placement.

b. *Local Control Equipment*

Closed loop traffic control systems are very similar to time-based coordination technology. There are two configurations: external and internal. The external version houses the communications function and the supervisory control functions that allow the interface with the local controller on a separate chassis. The internal form is generally designed as a single module that slides into a slot in the controller chassis.

Unlike the external closed-loop system interface devices, the internal devices are capable of three functions: communications, time-based coordination, and local controller database modification. With the internal closed-loop system local hardware, it is no longer necessary to make a trip to the field simply to adjust a clearance interval, or a minimum green or any other controller setting. The change can be made from a computer in any location (e.g., central control, remotely).

Being able to change or modify controller settings requires an intimate interface between the controller design, the communications messages and protocols, and the central controller software and database. This level of integration precludes the possibility of using one manufacturer's local controller with another's off-street master or central computer. The capability comes, therefore, with a stipulation that all replacement and expansion equipment must come from the original supplier. However, with the development of NTCIP, applications such as the link from the field device to a hub computer or central computer can be implemented with any combination of products and manufacturers. These standards will revolutionize the traffic-control industry and make things happen in terms of communication interfaces and proprietary product restrictions and constraints.

An advantage of the external form of closed-loop systems is that the device can interface with virtually any modern controller. Many systems provide the capability to interface with three-dial, electro-mechanical controllers, as well.

#### c. *Controller-Master Communications*

Most of the closed-loop systems use a 1,200 bits per second, Frequency Shift Keying (FSK), Time Division Multiplexing (TDM) communication protocol. The system will work on leased telephone lines or on jurisdiction-owned cable. Most installations have been with city-owned cable. The ideal system would be where each local controller in the system is addressed once per second by the master. Typically, the data transmitted from the on-street master to the local controllers are commands to switch to a particular timing plan, or data changes to the database of a specific controller. There are three categories of return messages: status data, signal display data, and detector data. This data need not be communicated on a once-per-second basis for every intersection and, therefore, different schemes (e.g., once per 30 seconds, once per minute) could be configured to make up the 1,200 bits-per-second capacity.

#### d. *On-Street Master*

The primary function of the on-street master is to select the timing plans for a group of intersections, to process and store detector count information, and to monitor equipment operation. The following traffic-responsive technique demonstrates a typical algorithm used in closed-loop systems, and is found in the Computerized Traffic Signal Systems Training Course.

All detectors are assigned to groups. There is one cycle group of 12 detectors. There are two offset groups (rightbound and leftbound) with a maximum of 12 detectors in each group. There are two split groups (main and cross) with a maximum of 12 detectors in each group. To select the cycle length, the highest value (some systems select the second highest or average value) of all the detectors in the group is identified. The cycle length is selected by comparing this value with parameters stored in a table that are associated with each of four cycle lengths. All systems have a form of hysteresis that prevents oscillating between different cycles when the measures are at the boundary levels.

The offset calculation would be similar but perhaps use a ratio of directional distribution to make the selection. For example, the ratio of the highest rightbound detector to the sum of the highest detector measure in both directions could be computed. The offset would be selected by comparing this ratio with values stored in a table. Typically three or five offsets are available with the middle offset representing balanced flow.

The split may be determined in a similar manner. Given below is an example that considers a two-dimensional matrix:

Cross Street Value	Main Street Value		
	1	2	3
1	SP2	SP2	SP3
2	SP2	SP2	SP3
3	SP1	SP2	SP2

As with cycle and offset, the detectors in the split group are searched for the highest value. The output values are mapped to a matrix. In this example, the mainstreet detectors are used as the column pointer and the cross street detectors are used as the row pointers. The entry in the table above represents the split selection; SP1 would favor the cross streets, SP2 would be the normal split, and SP3 would be a split that highly favors the main street. A characteristic of this type of system is that when SP3 is selected, all controllers in the system must operate on split three. This is not as restrictive as it first appears, as long as one can assign different values at each intersection to be assigned as split three. In fact, it is common for closed-loop systems to code the same values for each of three splits at some intersections so that no matter what split is selected by the master, one set of timing values would be used at a particular intersection. This would likely be done at minor intersections.

It should be noted that the numbers given by some manufacturers in terms of cycles that the system supports can be misleading. If one system supports 31 cycles, for example and another 15 cycles, it really does not make that much difference between systems if only three or four cycles will actually be used. Some systems state their timing plan capacity in cycles, splits, and offsets. Three cycles, splits, and offsets would correspond to 27 combinations or plans. Others count each independent set of values as a plan.

#### e. *Master-Central Communications*

All closed-loop systems are capable of using dialup communications between the central computer and the on-street master. With this form of communications, there is a separate telephone drop for each on-street master. Most telephone companies charge for the field drop on the same basis as a commercial telephone. Most users install a separate dialup line for the central computer, as well.

Communications between the central computer and the on-street master can take one of three forms: time synchronization, system command, and download data. A message transmission can be initiated by

a time-of-day event schedule or by operator action. The user has the option of issuing a command or downloading data. A typical command would be to update the master time of day with the value in the central computer. Another command would be to upload (send from the master to central) a particular page of data. A command typical of all closed loop systems is to initiate monitoring of a particular intersection. This command results in an intersection graphic being drawn on the central computer and the various green movements depicted by arrows and other graphic symbols. Depending on the system, the display of the intersection monitor information places a major load on the communications capacity.

Although all closed-loop systems can operate with dial-up communications, they work quite well with dedicated leased telephone lines and jurisdiction-owned cable. The dialup alternative offers the attractive qualities of being simple and generally inexpensive to install.

#### f. *Central Computer*

The central computer is used to:

- Set time and date. This enables the user to reset the computer clock and automatically reset the on-master and all local controller clocks to the same value.
- Display intersection. This allows a real-time display of single intersections (some systems allow the user to select a predrawn intersection from a library, and others provide the capability for the user to draw an intersection). With most systems, the communication link (telephone line) is occupied when the real-time display is ongoing. It is impossible, therefore, for the system to report any malfunctions if any are detected. The simplest way to deal with this problem is to allow the on-street master to retain the message in queue and to report the malfunction when the intersection monitoring is terminated.
- Modify master database. This allows manipulations of the database in the on-street master. This data is organized into five categories: the event schedule, the traffic-responsive parameters, detector processing parameters, data logging, and event logging.
- Modify controller and coordination data. Every point made above with respect to the master database holds true also for the controller/coordinator database. This is where first-time users of closed-loop systems appreciate the usefulness of full-screen editing. Another common function is the ability to copy all or part of the database for one intersection to another.
- Modify system parameters. Intersection addresses, communication line and slot assignments, type of monitor and video card, and numerous other system configuration data are included in this division
- Monitor system. When this option is selected, the computer is monitoring the communication port. When a call comes in, the central computer receives the message and takes the necessary action. Two types of messages are received when in this mode: a system error message and detector data.
- Prepare reports. The data generated by the closed-loop system is converted into information required by the operators of the system.

Figure 3.1, from the Computerized Traffic Signal Systems Training Course, provides a summary of the features for several closed-loop systems on the market today.

### Traffic-Adaptive Signal Control

#### a. *SCOOT*

SCOOT (Split, Cycle, Offset Optimization Technique) is the premiere centralized adaptive control scheme available. The fundamental technology of SCOOT grew from the development of the Traffic Network Study Tool (TRANSYT) in the late 1970s and early 1980s, and was developed in the United Kingdom by the Transport and Road Research Laboratory (now the Transport Research Laboratory).

SCOOT performs optimization at three levels. SCOOT measures vehicles at a detector ideally placed at least eight seconds of travel time upstream from the stop line. Every second, the central program predicts the profile of arrivals to the signal based on the profile measured at the detector. This arrival profile is compared with a departure profile based on saturation occupancy from onset of green to clearance of the queue. The lapse between departure and arrival profiles represent those vehicles delayed in a queue. These profiles are measures of a combination of detector occupancy and gaps, called *link profile units*. Determination of these units is one of the secrets of SCOOT.

The split optimizer in SCOOT evaluates the projected arrival and departure profiles every second. Five seconds before each change of signals within the cycle, SCOOT adds the delay from all movements that will end or begin at that change of signals. This delay is compared against delay calculated with the change of signals occurring either four seconds earlier or four seconds later. Of the three, the scenario that provides the best balance of delay for the movements being optimized will be implemented. Evaluation of this balance is controlled by user-defined preferences. To track trends, SCOOT will carry over one second of the four-second adjustment to subsequent changes of the signals, although the offset optimizer may make further adjustments.

At the beginning of the interval serving a user-designated combination of traffic movements, the offset optimizer projects the delay for all the movements of that intersection, based on the profiles measured in the previous cycle. This interval is called the *named, or nominated, interval*. SCOOT may adjust all the signal change times for that cycle four seconds sooner, four seconds later, or not at all. After this offset adjustment, the split optimizer may further adjust these signal changes based on profiles actually approaching the stop line at that time.

The cycle optimizer looks at the saturation levels of all intersection movements once each cycle-control period (2.5 or 5 minutes). The intersection with the highest saturation is considered the critical intersection. If the saturation of the heaviest movements at the intersection exceeds 90 percent, the cycle optimizer will add 4, 8, or 16 seconds to the cycle depending on the length of the cycle (4 seconds for the shortest cycles, and 16 seconds for the longest cycles). If the saturation is much less than 90 percent, the cycle optimizer will subtract the increment from the cycle. Because cycle adjustments are kept very small, they can always be accommodated immediately within a few following signal intervals, and lengthy transition periods are therefore not needed. The cycle adjustment will be added to the named interval; therefore, the named interval should be the longest and most easily varied interval in the cycle (usually main-street through movements).

Table 3.1. Features of Available Closed-Loop Systems.

On-Street Master Controller Unit	Automatic Signal/Eagle Marc 360	ECONOLITE KMC - 10,000	TCT MDM 100	SONEX S 80
Controller Units per Master	32	24	60	64
On-Street Masters per PC	256	240	16	14**
System Detectors per Master	2	1	4	10
Controller units per PC	8192	5760	960	896**
System Detectors per Master	64	32	32 per section/ 128 per master	32
Control Modes	(TOD, DOW, TOY) Manual, TRSP, Flash	(TOD, DOW, TOY) TRSP, Manual, Flash	(TOD, DOW, TOY) TRSP, Manual, Flash	(TOD, DOW, TOY) Manual, TRSP, Flash
Field Communications	• Dial-up • Twisted-pair, Fiber-optic, Radio, Coaxial & Telephone	• Dial-up • Telemetry, Twisted-pair, Fiber-optic, Telephone	• Dial-up, RS-232, Leased Cable • Telemetry, Twisted-pair, Fiber-optic, Leased Telephone	• Dial-up • Twisted-pair, Fiber-optic, Coaxial
Central Computer	• IBM Comp. PC-XT • 512 KB RAM • 360 KB Disk Drive • 10 MB HC • RS-232C output ports • MS DOS 3.0 • CGA, EGA or VGA color monitor • Hayes Comp. 1200/2400 modem • 80-column printer	• IBM Comp. PCAT • 512 KB RAM • 360 KB Disk Drive • 20 MB HC • Communication & output ports • MS DOS • EGA or VGA color monitor • Hayes Smart Modem 300/1200 • 80-column printer	• IBM Comp. PC-XT/AT • 640 KB RAM • 360 KB Disk Drive • 20 MB HC • Communication & output ports • MS DOS • EGA or VGA color monitor • Hayes UDS modem • 80-column printer	• IBM Comp. PCXT or AT • 256 KB RAM • 360 KB Disk Drive • 10 or 20 MB HC • RS-232 port • MS DOS • EGA, VGA color monitor • Sonex modem • 80-column printer
Reports (local alarms, MOEs, Communication and/or Detector failures, conflict monitor report, controller status, detector count logging, power failure, etc.)	Yes	Yes	Yes	Yes
Time Space Diagram	No	Yes	No	Coordinated green up to 32 intersections
Monitoring				
• Local Intersections	Yes	Yes	Yes	Yes
• System Map	Yes (EGA & VGA)	Yes	Yes	Yes
Max. No. of Reporting Events Stored	?	255		4 Days
Event Capacity for Time-based Traffic Patterns	180		200	Unlimited
On-Line Timing Generation	No	No	No	No

Table 3.1. Features of Available Closed-Loop Systems (continued).

On-Street Master Controller Unit	TRACONEX TMM 500	TRANSYT 3800 EL	BI TRAN MODEL 170	WAPITI MODEL 170
Controller Units per Master	31	30	32	48
On-Street Masters per PC	31	99	16	Unlimited
System Detectors per Master	1	1	1	1
Controller Units per PC	961	2970	512	Unlimited
System Detectors per Master	16	48	256	32
Control Modes	(TOD, DOW, TOY) Manual, TRSP, Flash	(TOD, DOW, TOY) Free Manual, Pre-empt, TRSP, Flash	(TOD, DOW, TOY) Manual, TRSP, Flash	(TOD, DOW, TOY) Manual, TRSP, Flash
Field Communications	• Dial-up • Twisted-pair, Fiber-optic, Coaxial	• Dial-up • Twisted-pair, Radio, Fiber-optic	• Dial-up, Leased Lines • Twisted-pair	• Dial-up • Twisted-pair, Fiber-optic • Any RS232 device
Master to Central PC				
Master to Load Units				
Central Computer	• IBM PC XT/AT • 512 KB RAM • 360 KB Disk Drive • 20 MB HC • Output parts • MS DOS • EGA or VGA color monitor • Printer	• IBM System 2 PC	• IBM PC XT or AT • 640 KB RAM • 1.2 KB Disk Drive • 10 MB HC • RS 232 port • MS DOS • EGA or VGA color monitor • Hayes Modem • 80-Column Printer	• IBM PC XT/AT • 512 KB RAM • 360 KB Disk Drive • 20 MB HC • CGA or EGA color monitor • Printer
Reports (Local alarms, MOEs, Communication and/or Detector failures, conflict monitor report, controller status, detector count logging, power failure, etc.)	Yes	Yes	Yes	Yes
Time Space Diagram	No	Yes	No	No
Monitoring				
• Local Intersections	Yes	Yes	Yes	Yes
• System Map	Yes	Yes	Yes	Yes
Max. No. of Reporting Events Stored	NI	NI	NI	200
Event Capacity for Time-base Traffic Patterns	NI	200	NI	64
On-Line Timing Generation	No	No; Comp. W/AAP	No	No

Setting up a SCOOT system first involves calibrating a range of parameters for each traffic movement in the network to ensure that the SCOOT model is working properly. These parameter adjustments require about the same level of effort during initial installation as conventional signal-timing calculations.

Once the movements are being properly modeled, the ranges within which the optimizers may work are defined, such as minimum and maximum cycle length, minimum movement timing, optimization preferences, etc.

SCOOT provides no optimization of phase sequence, although the systems that implement SCOOT allow complete flexibility in changing phase sequences by plan. SCOOT can then be used within these plans to provide adaptive control.

SCOOT detectors should be placed at least eight seconds of travel time upstream from the stop line, where possible, to allow the link profile units to be measured before the split optimizer performs its duty. Typically, these detectors are placed on the outbound lanes of upstream intersections, and tied to the upstream intersection cabinet. The assignment of a SCOOT detector for the downstream intersection is made within SCOOT.

SCOOT is a centralized algorithm based on once-per-second mandatory communication with the local intersection controller. None of the optimization steps is performed in the local controller. Consequently, the SCOOT optimizer is wholly dependent on the communications network and central computer for operation.

#### b. *SCATS*

Sydney Coordinated Area Traffic System was developed by the Roads and Traffic Authority of New South Wales, Australia, and utilizes a distributed, three-level, hierarchical system using microprocessors and minicomputers. The system architecture consists of a central monitoring computer at the central control center, remote regional computers, and local traffic-signal controllers.

For large systems with more than 400 signals, a VAX computer is recommended to provide system management support, data collection and analysis, data backup, fault analysis, and system inventory facilities. The central monitoring computer allows access to the regional computers for traffic data collection, data input, and monitoring. It performs the following functions without influencing traffic operation:

- Outputs traffic and equipment status for fault rectification.
- Stores specific traffic data for short-term or permanent record.
- Maintains the core image for each regional computer, and reloads the regional computer if required.
- Allows central control to monitor system, subsystem, or intersection, alter control parameters, manually override dynamic functions, or plot time-distance diagrams.

Each regional computer autonomously controls the intersections in its area. These computers are the heart of the SCATS system. They are usually installed at the center of the groups of traffic signals to be controlled in order to reduce the cost of the communications. They implement the signals by analysis of the detector information preprocessed by the local microprocessors.

The local controller, at the traffic-signal site, processes data collected from traffic detectors, makes tactical decisions on signal operation, and assesses detector performance. It also incorporates a software method of cableless link coordination (with 11 plans) through synchronous clocks. This provides a fall-back mode of operation that enhances total system security without the need for dual computer systems.

c. *RT-TRACS*

Real-Time Traffic-Adaptive-Control System (RT-TRACS) is a project to develop and field evaluate a real-time, traffic-adaptive signal control system similar to the SCATS and SCOOT systems, and suitable for use in the ITS environment. FHWA has awarded five independent contracts for development of a real-time traffic-adaptive algorithm for use in an Advanced Traffic Control (ATC) unit. One of these algorithms is the Optimized Policies for Adaptive Control (OPAC), developed as an on-line signal timing optimization software and hardware control system. An Advanced Transportation Controller (ATC) processes data from upstream vehicle detectors and develops real-time timing plans including cycle lengths, offsets, and splits to be implemented by the local controller. The OPAC is being tested on the New Jersey State Route 18 to examine its application in a closed-loop system environment.

RT-TRACS provide four levels of control: system, district, section and intersection. Each level should be able to seek optimization within the constraints imposed by higher levels. The system level is the highest level and consists of all intersections connected in the network. This level will provide the means to execute global functions. The district level will be the next level of control. The system will be divisible into geographic districts of several square miles in size. Every intersection within the system will be required to be in only one district. RT-TRACS will support 16 districts, each with the ability to support functions that address a large area of a city. A section will be a logical cluster of intersections. Intersections may be assigned to one or more sections. There will be a minimum of 256 sections, but no limit to the number of sections to which an intersection can be assigned. The intersection is the lowest level in the hierarchy. RT-TRACS will be designed to control a maximum of 5,000 intersections, in order to accommodate universal control in large urban areas.

RT-TRACS will provide for short-term and long-term strategies. The short-term strategies respond to current traffic as measured by detectors, while the long-term strategies manage congestion control for fall-back to off-line optimization. In both cases, a combination of strategic and tactical control decisions will be used to identify the system control level to be used in each section and to set signal timings accordingly.

RT-TRACS will consist of a variety of signal-control strategies, one of which will be dynamically selected for operation at a particular set of intersections at any given time. This selection of signal-control strategies will be changed according to the time of day, the prevailing traffic conditions, and other appropriate circumstances (e.g., holiday, special event, weather). An option for RT-TRACS will be that it could be

operated with only a subset of the signal-control strategies available for use in those street networks and local jurisdictions that have no perceived need for the more sophisticated range of control strategies.

Owen et al (1997) describe RT-TRACS as consisting of five basic components: the first predicts traffic conditions given weather conditions, time of day, existing flows, incidents, and other traffic factors; the second component defines the sections in the network; the third component selects the appropriate control strategy for the specific section given the traffic conditions that have been predicted; the fourth component implements this strategy; and performance is evaluated by the final component. RT-TRACS will implement all three control strategies by generation:

- First-generation control strategies use a catalog of fixed timing plans, generated off-line, to control a network of intersections.
- Second-generation control strategies use timing plans that are generated in real-time based on predictions from detector data. These control strategies are not limited by a fixed number of timing plans.
- The third-generation of control strategies is the most progressive system that operates in real-time, and adjusts signal timings based on detected data in real-time (i.e., very responsive to changes in traffic conditions).

Owen et al (1997) discuss the five prototype third-generation control strategies being developed under contracts from the FHWA and present early results of the conceptual evaluation of these prototypes in terms of potential strengths, weaknesses, and applicability. The five prototypes follow.

- University of Minnesota - Highly distributed architecture with two levels of control: Local Area Controllers (LACs) and upper level-overseeing LACs. Each LAC is managed by a controller using a program called CARS. CARS selects phase lengths for each intersection of the LAC in real-time based on mesoscopic simulation of the subnet that will influence the intersection. It adjusts the current green phase one intersection at a time, treating the intersections in user-specified order of importance.
- PB Farradyne Systems and University of Massachusetts - Low Level Optimization Policies for Adaptive Control (OPAC) design - Each subnetwork is considered independent and can transition between the uncongested and congested modes based on MOEs and thresholds. For uncongested networks, OPAC uses a level of control at the local intersection that determines the phase on-line and a network level for synchronization. The congestion control process in OPAC generally attempts to maximize throughput by selecting the phase that will pass the most vehicles through the intersection.
- University of Arizona - Composed of the main controller, called RHODES; APRES-NET, which simulates platoons; REALBAND, a section optimizer; PREDICT, which simulates individual vehicles; and COP, a local optimizer. The prototype is a hierarchical control system and has two levels of optimization: the global optimization and the local optimization.
- Wright State University Intelligent Systems Application Center (ISAC) - This prototype selects the best fixed-time plan for each independent network from a set of precomputed fixed-time plans. It then

modifies the current timing plan temporarily in real-time, based on local traffic detection. For local optimization, each intersection can modify the recommended fixed-time plan. For global optimization, the fixed-timing plans are generated for each network and for selected sets of conditions using an off-line, fixed-time signal network routine.

- Maryland/Pittsburgh - This prototype uses a highly distributed control, with most of the intelligence residing at the local level. The network level model operates in a supervisory capacity.

Table 3.2 presents early results of the conceptual evaluation of these prototype systems. They were interfaced with CORSIM for evaluation purposes.

### Traffic Controllers

Traffic controller technology has been divided into two camps represented by two different specification strategies. Both were developed in the mid-1970s, and both are now being superseded. But these two approaches represent nearly all the installed infrastructure of current signal systems.

- a. *NEMA TS-1*. The National Electrical Manufacturers Association (NEMA) developed performance specification TS-1 for traffic-actuated controllers. The specification is functional; only the operation of the controller (plus its physical and environmental requirements) are included. TS-1 describes what the controller must do, and describes the interface between the controller and cabinet. The NEMA specification does not set any requirements for user interfaces or system interfaces. Each manufacturer has developed proprietary interfaces in accordance with the need of its customers.

The NEMA specification first specified a consistent approach to phasing. In NEMA usage, a *phase* is the sequence of green, yellow, and red intervals for an individual traffic movement. In most intersections, two compatible phases will be allowed to display green at any given time.

NEMA did not specify hardware. The original TS-1 controllers used discrete solid-state electronics. Since that time, controllers have migrated to advanced microprocessors, and now provide a host of features not required by the original specification. Because the internal architecture of the controller is not specified, software for the controllers must be developed by the manufacturer and that software will work only with that manufacturer's product. Generally, software is built into the controller and is not accessible by the user.

NEMA did specify the cabinet interface. The TS-1 specification uses three round military-specification connectors to provide discrete signals to the controller field-wiring back panel.

Features are manufacturer-specific, and NEMA controllers are therefore not interchangeable within systems without a separate translator device.

- b. *Model 170*. Around the same time as the NEMA TS-1 development, the California Department of Transportation, the City of Los Angeles, the New York State Department of Transportation, and the Federal Highway Administration joined forces to develop an open-architecture general-purpose microcomputer for traffic control. The resulting Model 170 controller specification requires a specific hardware architecture and processor. Improvements in the specification have been limited to backward-compatible enhancements.

Table 3.2 Conceptual Evaluation of the Prototypes.

Prototype	Strengths	Weaknesses	Applicability
Arizona	Automated setup Amendable to lab testing Consistent with responsive objectives	Complexity (four components) Potential excessive computational time	Arterials and widely spaced grids Undersaturated conditions only
ISAC	Simplicity Amendable to lab testing	Unspecified number of fixed-time plans required Excessive detector requirements Does not update the timing plans Inconsistent overall responsive objectives	Any configuration that accommodates a fixed-time plan Undersaturated conditions Act in transition between fixed-time plans and fully responsive control
Farradyne OPAC	Extension of tested isolated intersection techniques	Theory not well documented Setup complicated Programming structure	Arterials with widely spaced intersections Undersaturated conditions with possible extension to saturated
Maryland/Pittsburgh	General applicability Based on proven theory (hydrodynamic wave theory)	Global optimization Setup and detectorization Programming structure Not easily tested	Saturated and undersaturated conditions Diamond interchange, grids and closely spaced intersections
Minnesota	Overall design structure Distributed approach	Implementation Not amendable to lab testing Questionable real-time applicability Proprietary automated setup routine	Adaptable to different intersection configurations

The Model 170 uses software developed by a third party. The user has access to the software, which work equally well with all manufacturers' products.

The specification also requires a standard serial interface for connecting the controller to systems. The interface with the cabinet is defined by a large, square connector carrying discrete signals to the controller back panel.

Because the specification defines only hardware, the functionality of the controller is entirely contained with the software. Model 170 controllers have been programmed to act as traffic controllers, variable-message sign controllers, ramp meters, field masters, and other traffic-system devices.

Model 170 controllers are brand-independent, and therefore provide interchangeability in all installations without the use of translator devices.

In the last few years, two new controller technologies have emerged to provide the advanced functionality needed by ITS technologies.

- c. *NEMA TS-2*. NEMA completed a specification for two variations of advanced controller in 1992. The TS-2 specification is similar to the TS-1 specification in that functionality is defined without imposing hardware standards. As with TS-1, the functionality of the controller is defined by built-in software that is not accessible by the user.

The TS-2 specification defines two grades of controllers. Type 1 is a pure TS-2 controller intended for new systems and installations. The Type 2 controller provides TS-1 cabinet interfaces to ensure backward compatibility with existing cabinets.

TS-2 specified a cabinet interface based on data transmission rather than discrete signals. The cabinet bus interface uses the RS-485 standard with the Synchronous Data Link Control protocol (SDLC). The cabinet bus interface is intended to connect the controller, the malfunction management unit (conflict monitor in TS-1 controllers), the detection system, and the terminals and facilities unit (the back panel). The use of the bus interface greatly reduces the complexity of signal controller cabinets by relieving the need for the hundreds of conductors required to move discrete signals around the cabinet.

The TS-2 controller defines a serial connection for communications with the system, but does not specify a communications protocol for that connection. Because the software is built into the controller, the lack of a defined system communication protocol has been a gaping hole in the specification. NEMA has sought to fill this gap by leadership and active participation in the development of the National Transportation Communications for ITS Protocol.

- d. *Model 2070*. The California Department of Transportation led a loose consortium of interested users in the development of an advanced open-architecture transportation controller. The original concept was called the *Advanced Transportation Controller*. Eventually, the concept solidified into the now-finalized Model 2070 controller standard.

The Model 2070 employs the open-architecture VMEbus industrial control computer. VME stands for Versa-Module Europe, and derives from the old Motorola Versabus. The use of an industry-standard computer architecture allows the installation of aftermarket processors and other devices in the controller. The VMEbus provides bus arbitration, which makes it possible for multiple processors to access the same resources within the controller.

The Model 2070 specification includes the processor, the system communications modules, and the field I/O module. The cabinet interface is provided by a Model 170-style square plug, making the 2070 cabinet-compatible with older Model 170s. The 2070 also includes an RS-485 port, which allows interface with NEMA TS-2 cabinets (assuming the software supports the port, which is not required by the specification). System communications are handled through asynchronous serial ports.

The Model 2070 controller is the first to provide a conventional real-time operating system and control programming in a high-level language.

As with the Model 170, software is provided by third-party developers, and completely defines the functionality of the controller.

### Arterial Highway Advisory Radio

The primary use of Highway Advisory Radio (HAR) is to provide real-time traffic information at key locations along major arterials. The information content of a HAR message can be much greater than that displayed on a dynamic message sign, and can use either live messages or prerecorded messages.

A thorough discussion of HAR can be found in Section 2.9.

### Arterial Video Surveillance

Video surveillance systems (CCTV) are systems used to verify and monitor traffic and incidents. They are also used to determine the type of assistance required. Each system consists of various elements including camera units, a controller cabinet housing the control equipment, and the communication system that connects the camera to a control center. The primary objective of an arterial CCTV system is to provide surveillance of arterial sections, intersections, visual confirmation of incidents, and information on the types of assistance that will be required.

A thorough discussion of video surveillance can be found in Section 2.7. However, there are some differences between freeway and arterial video surveillance. Some applications that are unique to arterial video surveillance follow.

- A camera viewing a single intersection in an urban area is commonly mounted on a building and might use a fixed lens. That particular camera might not need to have the capability of a remote controlled pan/tilt/zoom.
- Because many urban arterial are well lit, street lighting is usually available in urban intersections. This makes a color camera well suited, since these cameras require high lighting conditions.
- Using cameras to observe and/or verify the unused vehicle capacity on surface streets before diverting freeway traffic caused by incidents, reconstruction, special events, etc.
- Evaluating signal timing for arterials and verifying coordination of signals.

### Arterial Video Image Processing

These detection systems use microprocessor hardware and software to extract real-time traffic flow data through analysis of video images collected by a series of cameras mounted over roadways. These detector systems are discussed in Section 2.6. However, some distinct features and applications of these systems for surface arterials follow.

- Care must be taken in the mounting of the cameras, as there is a requirement that all approaches to an intersection may be observed so as to place detectors. If this is not possible with one camera, more than one unit should be placed for a larger coverage.
- Used for intersection detection (just like inductive loops), intersection traffic counting, intersection surveillance, queue length detection.

- Intersection applications where only presence detection is required and where the intersection traffic controller handles data storage and traffic-management-center communications functions.

### Arterial Detection

Detector technologies were discussed in Section 2.6, including technical sophistication, cost, and operational advantages and disadvantages. Accuracy of detection systems, as well as reliability, become important issues when dealing with arterial systems and intersection control. There is less room for error when considering intersection detection and control as opposed to the use of these detectors for freeway management and control, including traffic counting. In addition, the output type (e.g., relay, solid state) is important in arterial detection as the relay type fails on contact closure, thereby providing a constant call as opposed to no call (i.e., providing maximum green for that phase as opposed to no green at all). In addition, the location of detectors in traffic-signal control is different than when used in freeway systems. Care must be taken in selecting link, lateral, and longitudinal detector placement.

## 3.1.3 CASE STUDIES

### City of Richardson, Texas

John Black ([www.startel.net/atms/RFP.HTM](http://www.startel.net/atms/RFP.HTM)) presents specifications that were used to solicit proposals for an Advanced Traffic Signal Management System in the City of Richardson, Texas. The City conducted extensive tests on the equipment submitted between the period of January to December, 1995. It negotiated a contract with Naztec, Inc. of Sugarland, Texas and began a 6 month operational test of all system hardware and software in March, 1996. Naztec passed the operational test on September 1 and all controllers, conflict monitors, modems, and system support is on order and should be fully functional by January, 1997.

The specifications included such items as:

- Minimum System and Controller Requirements
- Desirable System and Controller Features
- Hardware and Software Requirements
- Future Software Enhancements
- Project Requirements
- Controller Specification
- Conflict Monitor Specification
- CATV Modem Specification
- Excerpt from NTCIP Protocol

- Contract Requirements
- Specification for Traffic Signal Cabinets
- Specification for a NEMA Conflict Monitor Tester
- Specification for Loop Detector Amplifiers
- Annual Loop Detector Installation Contract Specs

In addition, John Black ([www.startel.net/atms/COMCOST.HTM](http://www.startel.net/atms/COMCOST.HTM)) provides a Present Value Analysis for Selecting a Communications Medium for a Traffic Signal Control System in Richardson, Texas. This analysis can be found in Appendix J.

### OPAC

The Optimized Policies for Adaptive Control (OPAC), one of five candidate signal control system developed to work within RT-TRACS, has been installed and undergoing testing in Middlesex County, New Jersey. Early findings indicate that the system reduced travel time by 27 per cent on the arterial being tested and the number of stops by 55 per cent in over-saturated traffic conditions during the long afternoon peak period. Mean time for the whole route under OPAC was 783 seconds compared to 1053 seconds using regular coordinated, semi-actuated signals. Average stops per vehicle were 7 compared with 15.6. The most significant improvements were achieved in a short section of highway with traffic signals close together, while average stops dropped from 13.2 to 4.5, and average time in this section from 730 seconds to 457 seconds (Peter Samuel, September, 1996)

### SCOOT

The city of Anaheim, California is installing a SCOOT-based Urban Traffic Control System (UTCS), to form part of the city's Advanced Traffic Control System Field Operational Test. This test will determine the benefits of adaptive traffic control compared with conventional central signal system operations, and will evaluate the use of video image processing tools to support the real-time data needs for advanced traffic control. The city's current UTCS system will be integrated with the adaptive SCOOT system. SCOOT will be implemented at 31 intersections in the vicinity of Disneyland, the Convention Center, Anaheim Stadium, and the Arrowhead Pond Arena (Traffic Technology International, June/July 1996).

San Diego's new signal-control system, the Split, Cycle, and Offset Optimization Technique (SCOOT) responds automatically to variations in traffic flow, based on real-time information fed from detectors embedded in city roadways. A central minicomputer communicates once per second with SCOOT intersections, recalculating signal timing based on the up-to-minute information it receives.

SCOOT is currently concentrated on two city roadways. One is a six-lane major arterial serving commercial and light-industry areas as well as the Miramar Naval Air Station. The other provides access to San Diego's stadium, home to approximately 250 events each year. After San Diego evaluates these initial installations, the city will expand the SCOOT system. So far, results are encouraging: other areas with SCOOT systems report significant reductions in travel times, with decreases of up to 11 percent during peak periods.

### 3.1.4 EVOLVING TECHNOLOGIES

#### Spread-Spectrum Radio Traffic Interconnect

A Field Operational test that will evaluate the use of spread spectrum radio as a traffic signal communications device within the Los Angeles ATSAC signal system. The radios will be tested in a network of signals to determine their ability to reliably reroute communications links; work in various geographies; provide for large-scale, once-per-second communications; and determine the cost-effectiveness of using this technology.

#### Real-Time Traffic-Adaptive Signal Control

As discussed above, a prototype real-time, traffic adaptive control system (RT-TRACS) is under development and will be completed in 1997.

#### Advanced Traffic Controller (ATC)

This is a modern, open architecture, easy-to-integrate traffic control and communication system (under development) that will be deployed for most traffic control applications including: adaptive intersection control, integrated corridor management (loop detection, ramp metering, CMS control, etc.), communications, electronic toll and traffic management, video detection and surveillance, AVI, and other ITS applications. The SmartATC is being designed to Caltrans specifications and is being developed to overcome the limitations of the Model 170.

#### Common Information Database

Real-time management of traffic and transit operations in urban areas typically involves multiple jurisdictions and agencies, each responsible for traffic management within a defined area. Basic data needs between multiple traffic management centers may include: a center's need to be able to monitor the operation of selected other centers; a center's needs to be able to monitor the operation of selected field devices (transit vehicle, traffic signals, CMSs, etc.) managed by another center; a center's need to be able to issue commands to selected field devices managed by another center.

#### Integration of Control/Monitoring Systems

Integration of multi-agency control and monitoring systems allows different control centers and agencies to make system decisions and disseminate information to the motorist based on conditions in other systems.

#### SOURCES:

- *An Evaluation of Real-Time Traffic Adaptive Control Prototypes*, 1997, Submitted to TRB by Larry E. Owen, Charlie M. Stallard and Deborah M. Glitz.
- *Peak Traffic Problems Reduced*, September 1996, by Peter Samuel, ITS international.

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