Implementing a Traffic Signal Surveillance System

BY NAZIR LALANI AND ROBERT KOCHEVAR

In 1989, the City of San Buenaventura, California, population 90,000, decided to implement a traffic signal surveillance system. The city is located on the Pacific Coast, 75 miles north of Los Angeles, and maintains 90 signals, 30 of which are coordinated by systems connected to two field master controllers. Another 40 signals are coordinated using time-base coordination. The remaining signals are not coordinated. City staff decided to implement a surveillance system to address the following needs:

- Alarm Reporting—In the event of a signal failure, the surveillance system automatically notifies staff instead of relying on reports from police personnel or citizens.
- Malfunctions—The system allows city staff to check for various malfunctions that are likely to affect the efficiency of a coordinated traffic signal system, such as loss of signal coordination, loss of signal timing data due to power failures, controller software problems, and loss of communication between signals.
- Signal Timing—The system provides city staff with the ability to adjust and fine tune signal coordination timing from a central signal timing database rather than having to go out to signals in the field to adjust signal timing. The system also facilitates the implementation of signal timing for special events.
- Traffic-Responsive Operation—The system allows selection of the best timing plans based on volume/occupancy measurements made by system detectors.
- Viewing Real-Time Operation—City staff can view the operation of any signal in real time from City Hall or the maintenance yard. The system can also track and accumulate data on most types of problems and events.

The surveillance system implemented by the city utilizes readily available second-sourced components coupled with distributed computing power to provide control and surveillance of large numbers of intersections using simple, relatively inexpensive equipment. The system is an effective tool to manage traffic and is easy to operate and maintain. The central component of the system is a personal computer with color graphics capability and a communications program utilizing multi-tasking that operates in the background, allowing the personal computer to be used for word processing, spreadsheets, or other applications while still monitoring the system.

The system is composed of three levels of decision making: the central surveillance computer, the field master controller, and the local controller (see Figure 1). This results in decisions being made at the level closest to the level most affected by the results of the decision. Consequently, the system can tolerate communications interruptions with less degradation in operation than traditional centralized systems. It also results in large numbers of intersections being controlled using very few communications circuits.

The central surveillance computer supervises the operation of the field masters and performs as a surveillance center and central database. It also uploads and downloads specific coordination data and timings to the field masters and then from the field masters to the local controllers. The central surveillance computer maintains a central database of operating parameters utilized by the field master and local controllers. It accumulates data for reporting purposes (alarms, operational changes, detector counts, and occupancies). In addition, with the color graphics monitor, an operator can view the operation of any single intersection or certain groups of intersections within the system. Each intersection can have a different screen presentation. Intersection geometric layouts can be easily created by the operator.

The middle level of control is the field master controller. Field master controller hardware can be identical to that of the local controllers, but is programmed differently. The field master ensures proper synchronization of the local controllers connected to it and selects operating plans either in response to traffic demands or by time of day. Another of its tasks is to constantly determine the

Conversion Factors

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status of each local controller and to communicate any significant changes to the central surveillance computer. In traffic-responsive operation, the field master selects or modifies coordination plans based on vehicular counts and occupancies from system detectors.

The local controller not only performs the operations of an eight-phase traffic actuated or pretimed controller, but also acts as a communications processor, data accumulator, and time-base coordinator. The local controller directly implements all coordination functions (hold, forceoff, etc.) for each coordination plan. There can be up to eight system detectors connected to each local controller. The system detectors are used to count the vehicles that pass over the detector and to calculate the percentage of time the detector is occupied. In the event of a field master or communications link failure, the local controllers revert to time-base coordination.

The central surveillance computer is linked to each field master through a dial-up telephone circuit. It is possible that the city may eventually convert to its own dedicated lines if reliability and cost of testing telephone lines become an issue. The central surveillance computer communicates with up to 16 field masters. The communication process throughout the entire system is highly compressed. For example, system detector data is transmitted from the local controller to the field master only when needed. The compressed process allows up to 32 local controllers to be monitored and controlled by one field master over a single four-wire circuit. The software is capable of automatically establishing control of the traffic signals from any power-down condition. This includes a power failure or manual shutdown and subsequent turn on of power, with the restart procedure able to return the master computer to full operational status. The city elected to implement this type of central computer signal surveillance system for the following reasons:

- The coordination of signals does not rely on the central computer. Therefore, if communication between the central computer and the field master is lost, the coordination of signals remains unaffected. For many existing systems that rely on the central computer for signal coordination, when communication with the central computer is lost, signal coordination is lost.

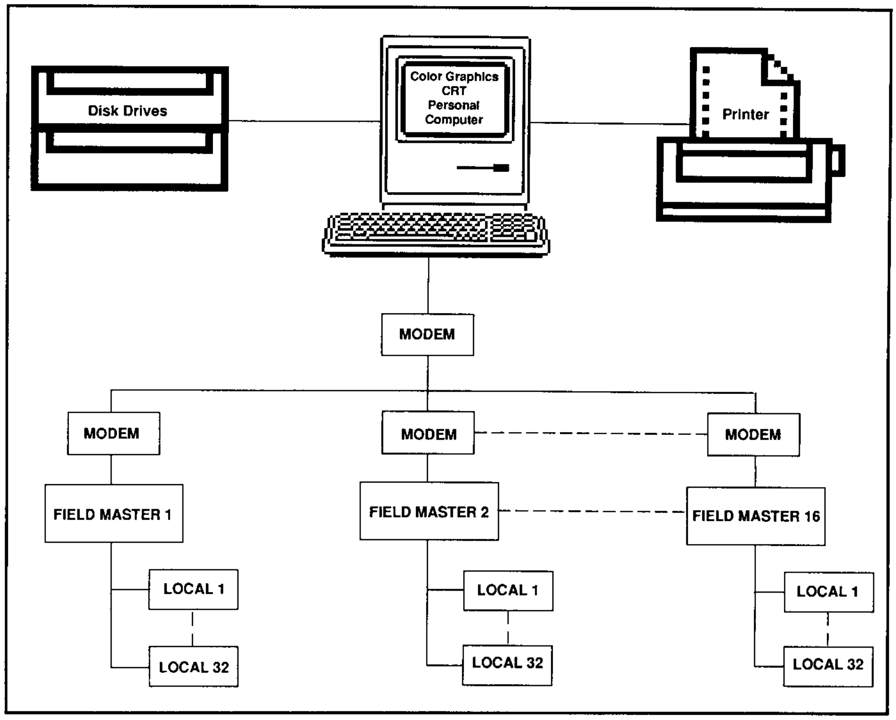


Figure 1. Traffic signal control and surveillance system.

- The cost of implementing the system is low since it relies on standard microcomputer equipment with voice-quality dial-up telephone lines as the communication link between the central computer and the field master. The system also utilizes the existing field masters and local controllers that are already in place.

System Contract and Work Scope

In order to ensure that the system had all the capabilities desired by the city and that the contractor installed the system correctly, the city prepared a contract with an attached work scope detailing the tasks to be performed. The system specifications were also attached to the contract. The main items included in the contract, work scope, and specifications are summarized here.

In order to fully and accurately describe the tasks to be performed by the contractor during installation of the surveillance system, a scope of work was attached to the contract. The work scope detailed the following information.

Hardware Configuration

This section of the work scope specified that the system structure had to be composed of a central surveillance computer, Type 170 field master, and local controllers.

Tasks

This section of the work scope specified the tasks the consultant had to complete in order to install a traffic signal surveillance system for the Victoria Avenue corridor, a 13-signal system located in the city and the first to be connected to the surveillance system (see Figure 2). The consultant was required to deliver and install the necessary equipment in City Hall and the maintenance yard. The system was to be connected to the Victoria Avenue on-street field master. The software was to be installed in the local controllers and the on-street field master. The system was to be tested to make sure it operated correctly, and city staff was to be trained to operate the system using documentation for the system provided by the contractor.

Documentation

The documentation provided by the consultant had to contain details of how the system was developed, how it operates, and maintenance procedures. The documentation had to include 12 copies, with continuous updates of all documents to be provided when revisions occurred and became available. Documentation includes, but is not limited to,

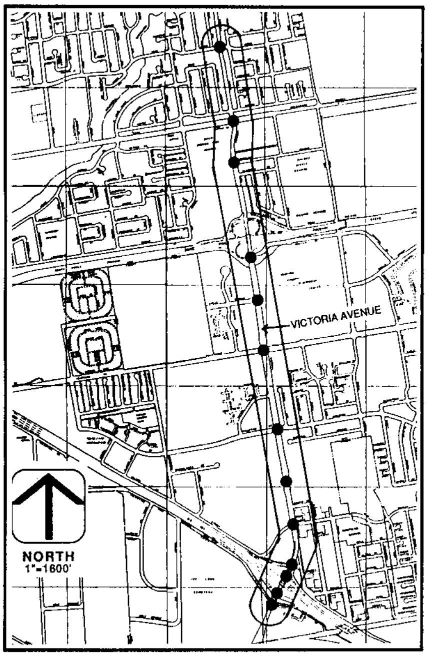


Figure 2. Coordinated signals on Victoria Avenue.

hardware and software data, wiring diagrams, parts lists, troubleshooting procedures, software use descriptions, and maintenance procedures.

System Testing and Acceptance

Testing did not begin until all the required equipment had been delivered and installed and was functioning properly. The contractor had to submit a test plan procedure for review and approval by the city. This test plan had to include the tests to be performed, schedule for testing, responsibilities, testing procedures, a list of contractor personnel who had to perform the tests on-site, success/failure performance criteria, and test suspension or restart procedures. The operations testing had to demonstrate the operation of all features supplied by the system contractor. The contractor had to provide on-site personnel for this testing and be responsible for set-up and actual demonstrations of system features. All features had to be tested for operational conformity with the specifications, contract proposal, and contract.

Acceptance testing did not commence until the operational testing was successfully completed and was to be viewed as multiple tests being run simultaneously. The intent of the acceptance test was to show that the system could operate on a normal daily schedule and perform traffic control functions over an extended period of time with no system breakdown or interruption in service. The system acceptance testing was required to run for 30 days of continuous computer control operation. The contractor was responsible to correct any problems that occurred during that 30-day period. Once corrections had been made, the acceptance testing continued as outlined in the test plan. Final acceptance was only given after a successful acceptance testing period of 30 days with 720 hours of continuous problem-free performance.

Training Requirements

The contractor provided training in the installation, operation, troubleshooting, and maintenance of the system. The training was made available for up to eight persons named by the city. Minimum requirements included providing the following:

- Forty hours of on-site training for repair, maintenance, and troubleshooting of the local controller software operation, the master controller operation, communication lines, central processing equipment, peripherals, and the use of all specialized test equipment, and
- Forty hours of on-site training in the programming, operation, and troubleshooting of the computer control system and associated graphic and offline analysis programs.

Training also included teaching city personnel how to expand the software database and control parameters for additional intersections and detectors and hands-on training and demonstrations of the use of the system optimization package.

System Specifications

Local Intersection Controllers

The city specified that the surveillance system had to be compatible with existing Type 170 traffic signal control equipment and Type 400 modems.

Field Master Controller

The dual port Type 170 field master controller included an auto-dial telephone modem with proper connections, cable to match the field master controller type, and the following features.

Timing Plans. The Field Master can control a minimum of 32 intersections and contains an internal time-of-day/day-of-week (TOD/DOW) software clock that automatically corrects itself for changes from and to daylight savings time and also for leap years. The field master is able to select coordination plans manually by time of day or in traffic responsive mode. The field master is able to implement specific coordination plans, traffic responsive operation, and free or system flash operation by time of day. At least 32 time-of-day events are available to the operator to change the operating plan, schedule the plans on a repeating basis by day of week, implement events on any combination of days of the week, or utilize a completely different schedule for holidays.

Manual Override. Manual entry plan selection can override TOD/DOW selection. The user is able to manually select a particular timing plan either through the master controller keyboard or through the central office microcomputer.

Time Plan Selection. TOD/DOW selection is based on the master's time clock utilizing an alarm clock table similar to the local controller program. In addition to being able to select any of the nine plans or free operation, TOD/DOW settings are able to call for traffic responsive operation during certain periods.

Clock Synchronization. Four times per day, the master controller is able to synchronize all local controller clocks with its clock. If the local controller detects a loss of pulse from the master for three cycles, the local controller falls back to its internal time-base coordination selection. Upon restoration of the synchronize pulse, the local controller reverts to normal "under master control" operation.

Traffic Responsive Operation. System detectors located at the locally controlled intersections are designed to measure volume and/or occupancy for traffic responsive plan selection. The traffic flow data from the system detectors are transmitted from the local controllers to the field master once per minute. This information is then used to select the best coordination plan for existing traffic flow conditions.

Central Surveillance Computer

Surveillance. The central surveillance computer (CSC) provides a centralized capability to monitor and control the operation of signalized intersections. The surveillance computer is capable of two-way communications with up to 16 remote field masters to provide reports and logs of system operation, monitor intersection operation, allow centralized plan selection, and upload/download operating parameters. The surveillance computer receives and records system alarms and operational status information, system detector volume and occupancy data, and local intersection operating parameters.

Multiprocessing. The surveillance computer software is capable of multiprocessing, e.g., the operator might be performing word processing or another similar function while the computer simultaneously monitors the operation of all intersections within the system for changes in alarm conditions. The communications link from the field masters to the local controllers uses twisted-pair direct wire.

Alarm Reporting. The surveillance computer, when unattended, automatically polls the field masters and local controllers for changes in alarm and operating plan. It stores the reports on disk and prints out any changes. The following alarms are recorded: conflict flash (cabinet flash and stop time), cabinet flash, loss of communications, external control, manual plan selection, detector failure, cabinet door open, and keyboard data entry. It is also possible to report the alarm data sorted by date, location, and alarm type.

Software Specifications. The system surveillance application software includes automatic recording of alarm data, operating plan changes, system detector volume and occupancy, intersection detector counts; real-time split monitor data; real-time display of local intersection operation, arterial operation, systemwide alarm status, systemwide operational status; field master and local controller database comprising configuration data, phase timing and flags, detector timing, coordination timing and flags, time-base coordination schedule; time-of-day function outputs; and system detector assignments.

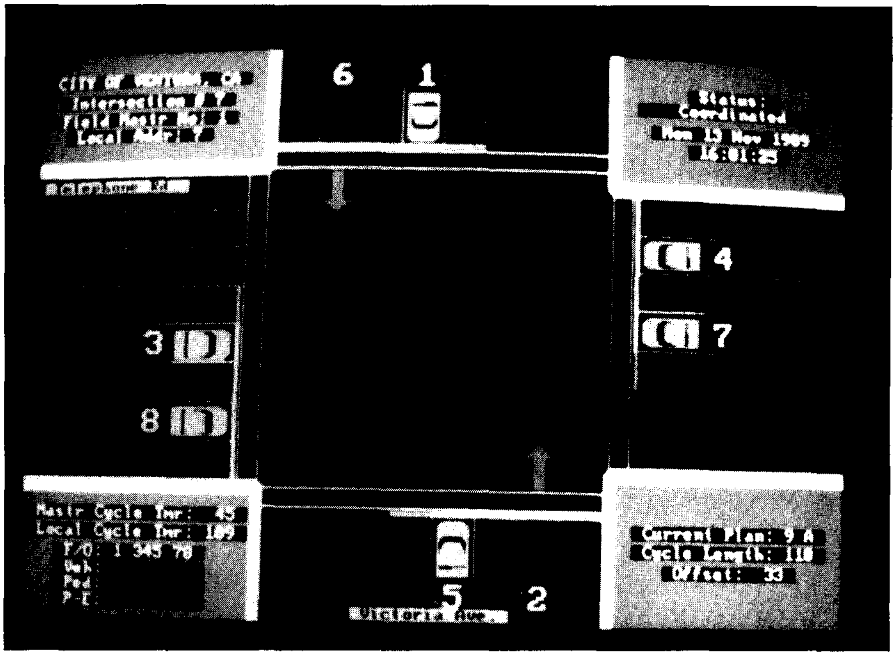


Figure 3. Real time intersection display.

Plan Selection/Displays. The operator has the ability to manually override the control plan in effect at any field master local controller and implement any other control plan in its place. The central surveillance computer is able to display on the color graphics monitor geometric representations of any selected system intersection. It is possible for the operator to create the geometric representations of every intersection for the real-time intersection display (see Figure 3). The following information is displayed in real time with the intersection geometrics: eight-phase signal indications, overlap signal indications, pedestrian signal indications, vehicle calls, pedestrian calls, operating plan, local cycle timer, master cycle timer, and preempt status.

Uploading and Downloading Timing. Field master and local controller timing parameters are stored on disk. The timing parameters when viewed on the color monitor have to be arranged similar to the timing sheets furnished with the controllers (see Figure 4). Timing changes to the database are possible using spreadsheet techniques. The system permits uploading of all operator-settable timing parameters from the field masters and local controllers to the surveillance computer to compare with the disk file and to update the disk file. It is also possible to download all field master system parameters, as well as all local controller phase and coordination timing and function operating parameters, except yellow and red clearance times. Complete downloads of all RAM (random-access memory) locations are available via the central computer or lap-top computer. The system provides an arterial display including main street green, current operating plan, and current alarm condition of all local controllers connected to that master. The CSC is able to compare an uploaded local intersection database with a previously developed database for that same intersection and highlight any differences between the two databases.

Equipment. Two central surveillance microcomputers were supplied and installed, one located at City Hall in Traffic Engineering and one at the maintenance road yard. The City Hall and maintenance yard CSCs are able to communicate with each other, as well as with the field masters. Each CSC includes an IBM-PC compatible 386 microcomputer, 1 MB RAM, EGA color monitor, 360K floppy disk drive, 40 MB hard drive, EGA color graphics card, battery-powered clock/calendar, printer buffer, second RS232C serial port, MS-DOS operating system, surge protector, Hayes smart modem 2400b or equivalent (internal), printer with stand and forms receiving tray, 101 keyboard with number pad, six cases of fanfold printer paper,

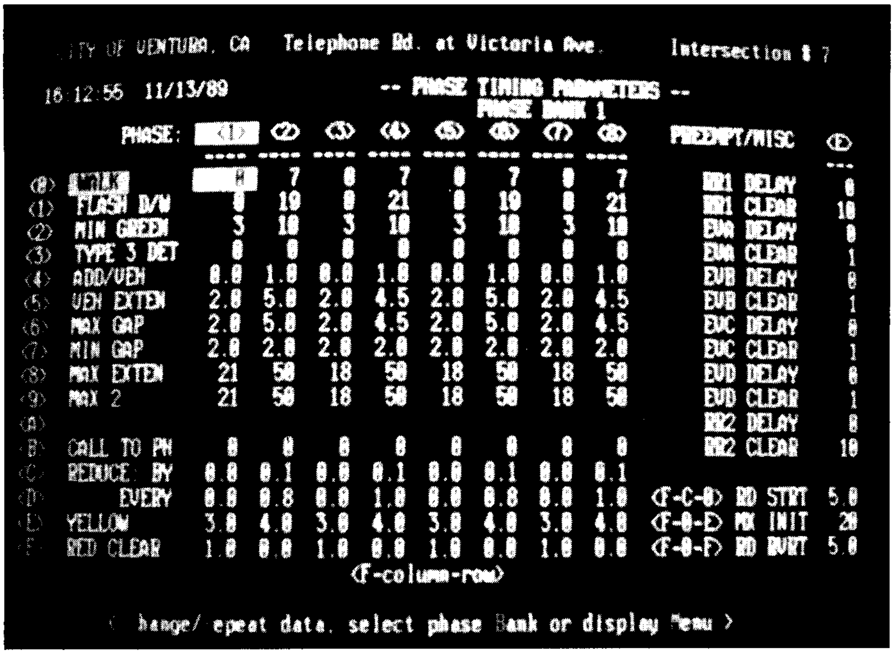


Figure 4. Signal timing data display.

back-up streaming tape, one compatible lap-top computer with 8086 coprocessor, and graphics mouse.

A lap-top computer was included in the equipment list to enable signal maintenance technicians to communicate with the field masters and local controllers from locations other than City Hall or the maintenance yard, especially outside normal work hours. The minimum characteristics for key equipment items were specified as follows:

- Color Monitor—Nominal 13-inch diagonal screen; 800 by 560 pixels; maximum dot pitch of 0.31 mm; digital and analog red, green, and blue inputs; 30 mHz bandwidth.
- Lap-Top Computer—Toshiba unit 1200 or compatible, internal Hayes compatible modems, portable battery-power capability, 1 MB RAM, 20 MB hard disk; and 3.5-inch disk drive.
- Line Printer—Minimum print rate of 200 characters/second, 132 printer positions/line, tractor paper feed, standard computer bond paper fanfold, bidirectional printing, and full line buffering.

All necessary cable and accessories needed to make this system function according to these specifications were provided by the contractor.

System Size and Capabilities. The central surveillance computer software had to provide the following capabilities without any modifications to the base programs:

- Intersections to be controlled—255 minimum
- Number of system detectors—500 minimum
- Number of intersection detectors—8 per intersection.
- Number of zone areas or subsystems—16 minimum, and
- Number of timing plans—500 minimum.

Multi-User Feature. The surveillance system is set-up with multi-user features so that both the CSC located in the traffic engineering office and the CSC at the maintenance yard have the same capabilities. A security system for accessing the CSC is provided as specified by the city. Both users have the capability of uploading and downloading signal timing, which is accomplished through the specifications of the security system. Both users utilize the master signal timing database, which is located at the maintenance yard CSC, so that any signal timing changes made at the traffic engineering office automatically update the master data at the maintenance yard CSC. However, only one user can access a field master at a time.

Emergency Notification. During work hours, the CSC is capable of notifying the maintenance yard clerical work station of any failure at critical intersections. During nonwork hours, the CSC notifies the on-duty signal technician via a pager system.

System Reports

The central surveillance computer is capable of generating all reports while the system failure monitoring is on-line. All reports are available on the monitor and in hard copy in report-type formats. Reports are available on a schedule determined by the operator.

Database Reports. The central surveillance computer provides the following database reports on historical volume data from system detectors: the information stored in the database on the timing plans for any intersection or subsystem, and the subsystem control information stored in the database regarding subsystem parameters, the real-time split monitor indicating actual phase timing per cycle during both coordination and free operation.

Status Reports Real-time intersection status reports provide information on status of vehicle phases, preempt information, operational status, and on/off special functions (current timing plan including offset and phase timing).

Color Graphics Capability The color graphics software has the capability to do diagram intersections (including pavement markings) in user-defined colors, observe the real-time operation of intersections, prepare text in various font styles, and observe in real-time the current operating plan, any current alarms, and main street green indications of each local controller.

System Security and Communications

The software has system security provisions that include user-defined passwords, multilevel security with passwords for each level, multiple passwords possible for each security level, and change passwords requiring the highest level of security clearance.

The field master is required to test the operation of each local controller and request status information from each local controller once every two seconds. The local controller responds with status for arterial greens, preempt, manual, flash, communications error, and current plan.

The status report from each local controller is updated and stored for transmission to the surveillance computer. Upon detection of any local controller having extended communication failures or going into unscheduled flash or manual operation, an alarm is logged for transmission to the personal computer. The field master polls the local controllers once per minute for system detector volume and occupancy data. The field master transmits a synchronization pulse to all local controllers at the beginning of each master cycle. The commands received from the CSC are able to do the following:

- Change at the field master any of the time-of-day or traffic-responsive parameters used for selection of operating plans and request current status of the field master and all local controllers, including communications, flash, manual, preempt, plan in effect, and mode of field master operation.
- Request real-time display of the operation of any selected local controller. The real-time displays include the current plan, cycle and offset, master and local cycle timers, the current condition of each phase (vehicle and pedestrian) and overlap signal, and demand status for each vehicle and pedestrian phase.
- Request system detector volume and occupancy data, as well as upload or download any or all local controller phase, coordination timing, or function parameters.

System Selection

The city made its selection,* from among the many surveillance systems now available, for the following reasons:

1. The central office computer equipment utilized off-the-shelf microcomputers, and communications could be via standard voice-quality telephone lines.
2. The system is compatible with Type 170 controllers, to which the city was converting all its local controllers, and uses a dual port Type 170 controller as the field masters. (Two of the city's interconnected signal systems were already utilizing a Type 170 controller as a field master.)
3. The system is capable of interfacing with the Type 170 controllers and software being used by the California Department of Transportation to control ramp intersections at freeway interchanges in the city. The controller software is compatible with the Type 170 controller software standards developed by the California Department of Transportation.

System Costs

The initial cost to implement a surveillance system for the 13 intersections on the Victoria Avenue corridor is summarized as follows:

Central office computer equipment (two work stations)	$10,000
Central office computer QuicNet software	17,000
Local intersection software (10 intersections)	3,000
On-street field master controller (one for this system)	2,500
System warranty	4,500
Staff training	3,000
TOTAL	$40,000

These costs were for the Victoria Avenue corridor, which was already interconnected. If the system were to be implemented for a series of independently operating signals, the cost of interconnecting the signals would have to be included.

Results

The implementation of the surveillance system has enabled the city to adjust signal timing much more quickly and efficiently from the office. Malfunctioning signals are detected and repaired more quickly. The system is able to track the type of malfunctions that affect specific intersections, which helps the maintenance crew to identify recurring types of problems, and maintenance technicians can communicate with the field masters and local controllers from remote locations via the lap-top computer.

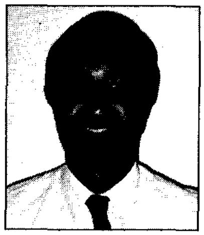
*BI Tran Systems, Inc., Sacramento, Calif.

Recommendations

The surveillance system has provided the benefits anticipated from a central traffic signal control system. The city plans to continue expanding the system to include signals on other corridors that are already interconnected. Eventually, the city plans to interconnect all the signals in the city and connect them to the surveillance system.

Based on the San Buenaventura experience, it is recommended that local agencies contemplating installing a central surveillance system include all the main features detailed in this paper. By doing so, agencies will ensure that the system performs all the tasks and provides all the features that are necessary for a state-of-the-art surveillance system at a reasonable cost. The type of surveillance system selected for implementation should be based on compatibility of the systems under consideration with the existing controller equipment in order to minimize cost. ▮

Nazir Lalani, *P.E., is currently transportation and traffic engineer with the City of San Buenaventura, California. Previously, he was senior transportation and development engineer with Santa Barbara County. Prior to coming to California, he worked as principal traffic engineer for the city of Lakewood, Colorado. Lalani graduated from Exeter University and subsequently obtained a master's degree in civil engineering from Arizona State University. He is a Member of ITE and is currently serving as president of ITE's District 6.*



Robert A. Kochevar, *P.E., is a senior transportation engineer with CRSS Group, Inc., in Denver, Colorado. He has more than 17 years of experience in transportation and traffic engineering in both the public and private sectors. Kochevar has participated in the design, installation, and operation of numerous traffic signal control systems. He is a Member of ITE and previously served as an officer of the Colorado-Wyoming Section. He has participated in many ITE committees at the section, district, and national levels. He holds a B.S. from the University of Illinois, and an M.S. from the University of Colorado.*