



Interstate 476 in Pennsylvania is the site for Traffic and Incident Management System.

Blending Technologies To Manage Traffic

Interstate 476 in Pennsylvania

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Surface transportation in the United States faces a number of challenges. Despite the fact that the United States has one of the best roadway systems in the world, mobility is declining and safety remains a serious problem. Inefficient movement of vehicles reduces productivity, wastes energy, increases emissions, and threatens the quality of life we enjoy. Safe, efficient, and environmentally responsible transportation is vital to the social and economic health of the nation.

— U.S. Department of Transportation,
*National Intelligent Transportation System Program Plan
Intelligent Transportation Systems, March 1995*

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In 1956 the U. S. Congress launched the ambitious Interstate highway system to enable high-speed travel for motorists across the nation. The Interstate program is nearing completion, yet its objective—to facilitate swift, safe, and efficient highway travel—is far from achieved. Statistics indicate that 70 percent of travel on urban interstate highways is severely congested during peak periods. The lack of potential for building new highways or adding lanes is compelling transportation planners and operators to develop new strategies to address traffic congestion.

Technology is increasingly viewed as an important part of the solution for improving the productivity and performance of existing transportation facilities. Ongoing developments in technologies are expected to facilitate the implementation of advanced traffic management systems (ATMS) that can improve the safety, capacity, and operational efficiency of the surface transportation system. In addition, cutbacks in military spending over the past few years has stimulated the development of new applications for ATMS purposes using advanced defense technologies.

ATMS provide tools to monitor traffic flow conditions, provide travelers with real-time information for making better travel decisions, and regulate traffic volumes on the basis of actual traffic conditions and travel demand. These systems also allow engineers to monitor critical transportation system performance parameters for use by planning agencies and system operators.

Several state departments of transportation and metropolitan planning organizations are currently implementing ATMS to reduce congestion and improve incident management. A recent study conducted by the Intelligent Transportation Society of

America has determined that 12 freeway operation centers, 85 local traffic control centers, 31 freeway service patrols, and 47 incident management programs are in operation or are being established across the country. See Figure 1 for major cities in the United States that have implemented or are implementing ATMS projects.

The successful implementation of ATMS demands a robust communications infrastructure and proven sensor, information processing, and control technologies. Since the application and system design of these technologies are relatively new to the traffic environment, the federal government and departments of transportation are conducting operational tests and early action programs. These tests and programs are expected to facilitate the agencies' ability to evaluate system performance, and will provide valuable experience in determining appropriate technologies and applications for full-fledged ATMS implementation. The programs are also intended to educate motorists and accustom them to facilities equipped with the new technologies. Among the priority corridors for the Pennsylvania Department of Transportation is Interstate 476, a major highway serving the Philadelphia region.

NATIONAL CONTEXT

Advanced traffic management systems have been successfully implemented in several cities in the United States, Europe, and Asia, and have proven to be efficient tools for managing traffic congestion and accidents on freeways and urban arterials. The Faster and Safer Travel Through Traffic Routing and Advance Controls (FAST-TRAC) project in Oakland County, Michigan, deployed in 1995, has eliminated serious injuries, decreased left-turn accidents at dangerous intersections by 89 percent, and increased vehicle speeds during peak and rush hours by 19 percent.

The Freeway Traffic Management System in Minneapolis, Minnesota, initiated in 1991, has resulted in a 25 percent decrease in accidents, a 20-minute reduction in response time to incidents, a 35 percent increase in average speeds during rush hours, and a 22 percent increase in freeway capacity. In Abilene, Texas, the Computerized Traffic Signal System, in operation since 1993, has reduced average travel time by 14 percent and delays by 37 percent, increased travel speeds 22 percent, and reduced carbon monoxide and hydrocarbon emissions by 10 percent.

The I-476 Traffic and Incident Management System (TIMS) project in Pennsylvania is unique among ATMS projects nationwide because it inte-

FIGURE 1
Deployment status of several intelligent transportation system projects in the United States as of 1995.

FHWA/URBAN ENGINEERS, INC.



grates ATMS hardware and software components using a variety of communications technologies. This project will be comprehensively evaluated in accordance with the Federal Highway Administration's Intelligent Vehicle-Highway Systems Operational Test Evaluation Guidelines. The implementation and evaluation of this project is expected to provide valuable information to PennDOT for planning future systems, and to other agencies that are planning to implement ATMS on a large scale.

WHAT IS I-476 TIMS?

PennDOT and the Pennsylvania Turnpike Commission manage more than 185 kilometers (115 miles) of interstate highways in the Greater Philadelphia Area (Bucks, Chester, Delaware, Montgomery, and Philadelphia Counties). PennDOT Engineering District 6-0, in cooperation with the Turnpike Commission, funded a master plan for implementing an advanced traffic and incident management system for the transportation facilities in the region. On the basis of the positive results obtained from other ATMS projects across the nation, the PennDOT TIMS program is envisioned to improve the operational efficiency of the existing transportation facilities in the region through traffic monitoring, quality traffic information for motorists, and real-time regulation of traffic flows.

Concurrent with the master planning effort, PennDOT pursued the design of early action programs on I-95 and I-476 to determine the best technologies for regionwide implementation. The TIMS on I-95 in the Philadelphia area has been operational since October 1993. A preliminary assessment of I-95 TIMS benefits, which included interviews with police, maintenance, and traffic reporting agencies, indicates that the system has improved overall traffic operations and is providing better traffic information to the motorists in the region. The incident response agencies indicate that the TIMS on I-95 has enhanced regional coordination of incident management. According to traffic reporting agencies, the information received from TIMS operators is more accurate, timely, and reliable.

I-476 is a 35-kilometer (22-mile) limited-access highway, opened to the public in December 1991, which traverses Delaware and Montgomery Counties in Pennsylvania. I-476 comprises eight interchanges including three freeway-to-freeway interchanges. Rapid traffic growth is already causing stop-and-go conditions during peak periods along certain sections of the route. The current

GLOSSARY OF TERMS

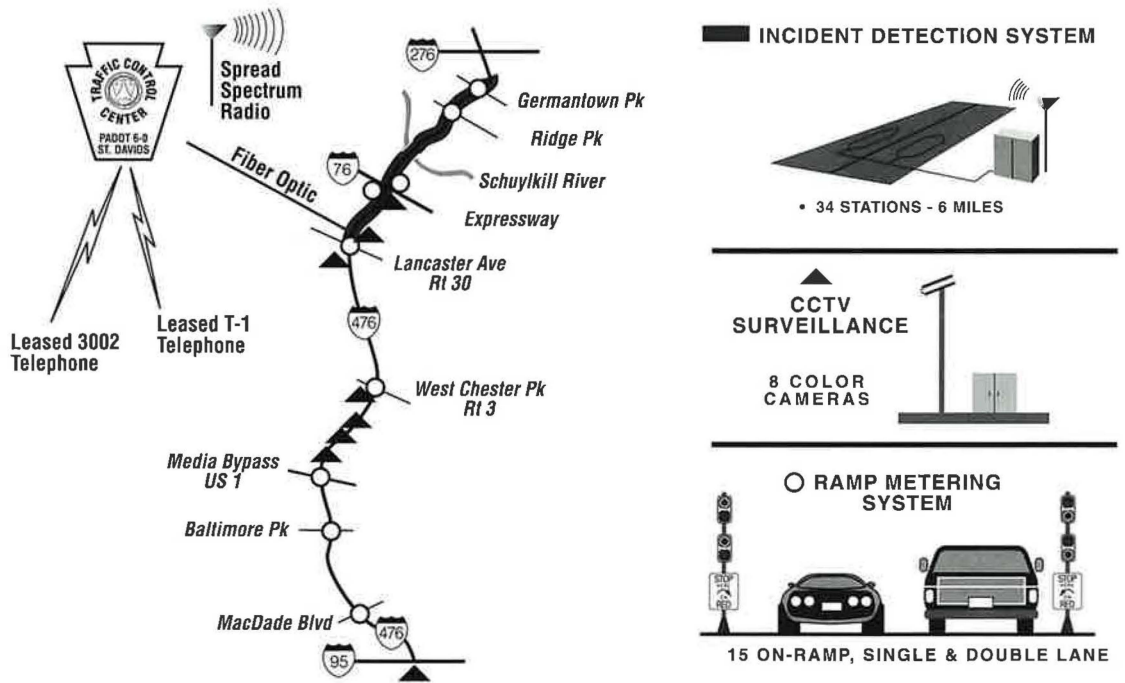
- Closed-circuit television system.** Point-to-point video system typically used for security purposes; it consists of cameras, lenses, camera housings, pan-and-tilt drives, video monitors, and cables.
- Fiber optic cable.** Made of one or more strands of glass fiber constructed to reflect light in an efficient and predictable fashion; has very large bandwidth and can transmit data, voice and video images.
- T-1 telephone line.** High-speed digital telephone line with a capacity for providing 24 voice-grade channels.
- Type 3002 circuit.** Dedicated voice-grade telephone line.
- DS-3 telephone line.** High-speed digital telephone line with capacity for providing 28 T-1 telephone lines.
- Spread Spectrum Radio.** Wireless communications system that uses a special modulation technique to spread energy of a transmitted signal over very wide bandwidth.
- Inductive Loop Detector.** Detector embedded in the roadway that senses change in inductance of its loop sensor caused by the passage or presence of vehicle over the sensor.
- Side-Fired.** When a device is mounted on side of and above roadway, pointing down at vehicles.
- DS-3 Multiplexer.** Combines 28 T-1 lines into one DS-3 line or divides DS-3 line into 28 separate T-1 lines.
- Video Encoder.** Digitizes and compresses high-bandwidth analog video signal for transmission on lesser-bandwidth digital transmission medium.
- Video Decoder.** Decodes digital signal transmitted by video encoder into analog video signal for viewing on video monitor.

average annual daily traffic on the highway exceeds 52,000 vehicles, and is projected to increase to 61,300 vehicles by the year 2010.

The early action program on I-476 blends conventional and advanced sensor technologies with several communications technologies for implementing an ATMS. The system also includes an integrated test bed for evaluating the performance of overhead-mount vehicle detectors, with provisions to evaluate several other detector technologies. The project will also evaluate several communications media for two-way transmission of traffic and control data between the ATMS elements in the field and the existing traffic control center (TCC).

The I-476 TIMS will include the following major systems: closed-circuit television monitoring, incident detection, ramp metering, and an advanced vehicle detector test station. These elements will use the following technologies to provide communications between the field elements

FIGURE 2
I-476 Traffic and Incident
Management System
overview.



and the TCC: leased T-1 telephone lines, fiber-optic cable, leased 3002 telephone lines, and spread spectrum radio.

The I-476 TIMS project is expected to be in operation in June 1996. The evaluation plan will be developed after the initiation of system operations and will be subject to the approval of PennDOT and FHWA before it is finalized. A system overview of the I-476 TIMS project is illustrated in Figure 2.

GETTING TIMS OFF THE GROUND

The design process involved field visits, literature research, visits to other traffic management centers, and coordination among several agencies. The field visits included bucket truck surveys to determine optimum camera coverage locations. Other surveys were conducted to determine the line of sight between the spread spectrum radio locations, and optimum cable paths between the field and TCC devices. The project team compiled literature and other related information from several manufacturers for all major components of the project. The technologies were researched and evaluated with respect to applicability of each to the traffic environment; functional requirements of the project; procurement, operations, and maintenance costs; performance and reliability in

other applications; compatibility with existing PennDOT systems and suitability for future expansion; and future product support by the manufacturer. Several equipment manufacturers were invited to demonstrate their products. The project team discussed design issues with other transportation agencies that had already implemented ATMS projects; reviewed evaluations of other ATMS projects; and visited other traffic management centers to research operational procedures, system design and capabilities, and performance of technologies for various applications. The performance of equipment that was installed as part of another PennDOT ATMS project was also evaluated. Throughout the design process, the project team closely coordinated with electric and telephone utility companies. Monthly design progress meetings were held with PennDOT and FHWA in order to resolve technical or coordination issues.

The bidding process has resulted in a time lapse of approximately six months between submission of the design and start of construction. Although such a period is common to highway projects, rapid developments in technology can have considerable impact on the original system design of an ATMS project, even in a short time. To overcome this problem, the project team is working closely with the contractor to make design changes to accommodate the latest technology. The design

team, construction management team, and PennDOT representatives meet with the construction contractor every two weeks to incorporate the latest technology developments into the project, resolve any construction issues, and ensure proper scheduling of construction activities.

HOW TIMS WORKS

The I-476 TIMS is anticipated to improve traffic flows during peak periods, construction, and incident conditions; reduce response time to incidents; improve motorists' safety; and improve incident management. The system is also expected to enhance PennDOT's coordination with the local incident response agencies, including state police, county 911 centers, and fire and ambulance services.

The operating procedures for the I-476 TIMS will be developed during systems initialization and will be refined during the course of normal system operations. The operations plan will document the procedures to identify and confirm an incident, coordinate with the agencies involved in clearing it, provide information to motorist advisory agencies, and dispatch incident response teams.

The system will be in operation from 5:00 a.m. to 7:00 p.m. during weekdays and during special events. A three-step process, described in the following sections, will provide incident detection, verification, and management from a central traffic operation center.

Pinpointing Incidents

The TCC will serve as a central clearinghouse for disseminating traffic information to the appropriate agencies for action. When an incident occurs on I-476, the incident detection system will alert the TCC operator by means of an audible alarm. At the same instant the computer will display color graphics of traffic flow conditions. The closed-circuit television system will allow the operator to continuously monitor the freeway to detect incidents. The operator may also receive cellular telephone calls from motorists, the state police, PennDOT maintenance crew in the vicinity of the incident, or traffic reporting agencies.

After receiving information on an incident, the operator will use the closed-circuit television system to verify that the incident has occurred. Once the incident is confirmed the operator will zoom in on the site of the incident to define its type (fatality, injury, property damage, lane blockage, or some combination) and determine the magnitude of response required.

If neither the incident detection nor closed-circuit television monitoring system is available at the reported incident location, the operator will coordinate with the state police, the traffic reporting agency, or both to determine and verify the occurrence of an incident and initiate a response.

Automated Response

When traffic congestion is confirmed by the central computer system, the ramp metering sites located upstream of the incident location will be activated automatically to regulate the traffic flow onto I-476. The ramp meters will regulate the traffic flow on the basis of the traffic congestion downstream of the ramp meter location and the magnitude of traffic demand upstream of the ramp meter location. This will reduce congestion upstream of the incident location and will also reduce the possibility of collisions at the ramp merging areas.

Operator Response and Monitoring

The operator uses facsimile, telephone, or two-way radio to communicate with the agencies responsible for dispatching emergency assistance and incident management services. Information will also be disseminated to traffic reporting agencies to inform nearby motorists of the incident. The TCC will coordinate with the following agencies to manage traffic and incidents:

- Pennsylvania state police,
- PennDOT maintenance crew,
- Southeastern Pennsylvania Transportation Authority for rerouting or adding bus service,
- The news media for radio and television broadcasts of traffic conditions (which will eventually receive traffic information from the I-476 TIMS automatically, in addition to live video images on request for nationwide television broadcasts),
- Local townships and municipalities, and
- Transportation Operations Coordinating Committee, a multiagency consortium and a traffic information clearinghouse for northern New Jersey, New York, and the I-95 corridor.

The operator monitors the conditions and records them using a videocassette recorder, if required. When the traffic flow improves, the ramp metering system will be deactivated. The operator will also maintain constant communication with various agencies that are managing the incident and disseminating information to motorists. Incident reports and videotapes will be developed for later review to refine incident management procedures.

ELEMENTS OF DESIGN

Closed-Circuit Television Monitoring System

The closed-circuit television monitoring system includes eight dynamic and low-light color cameras located at the critical sections along the freeway. The system uses a camera and a motorized zoom lens housed in an environmentally controlled enclosure. The enclosure is mounted on a pan-and-tilt drive to enable remote control of camera movement and focusing. The whole camera assembly will be mounted on a 12-meter- (40-foot-) tall pole or an existing sign structure. The closed-circuit television system will use T-1 telephone lines leased from the local telephone company, and a fiber-optic cable plant that will be installed by PennDOT for transmitting video images to the TCC.

A leased DS-3 telephone service at the TCC with a capacity of 28 T-1 telephone lines provides communications with the individual T-1 lines at the camera locations. A DS-3 multiplexer and individual data multiplexers and video signal decoders will be used at the TCC for each camera location to receive and decode the video signals and to transmit camera control signals.

The decoded video signals are brought back into a closed-circuit television switcher/controller system with the capacity to handle 64 video inputs and provide 8 monitor outputs. The switcher/controller will be used to program the sequencing of camera images on the video monitors to minimize manual interference.

The network manager is the heart of the communications system, hosting the software for network management, closed-circuit television switcher/controller, and video encoder and decoder control. The extensive network management features in the system enable the TCC operator to troubleshoot and isolate equipment malfunctions efficiently, thereby optimizing maintenance. Future traffic management systems in the region will be able to use the additional capacity available in the DS-3 circuit and the switcher/controller at the TCC.

Incident Detection System

The incident detection system will use the existing inductive loop detectors (ILDs) embedded in the roadway to sense traffic flow conditions in real time. The California Department of Transportation Model 170E controllers at each detector station will process the ILD signals to determine traffic flow parameters—including average vehicle volume, speed, and occupancy—and to transmit

the data to the central computers via a spread spectrum radio link. The central computers will process this data to determine traffic flow conditions and provide color graphic displays and audible alarms for rapid and easy interpretation by the operators.

PennDOT recently conducted a spread spectrum radio implementation survey to determine the radio frequencies in the vicinity that could interfere with or be hindered by the I-476 spread spectrum system, and to develop the spreading algorithms to minimize these interferences. The spread spectrum radio network is designed for a fault-tolerant operation that will accommodate intermediate radio or repeater failures without affecting system operation.

The system can automatically activate variable message signs to inform motorists of the traffic conditions ahead and to relay information to the news media for public broadcast. The variable message signs and dedicated link to the news media will be implemented in the future.

Ramp Metering System

The ramp metering system will be used to monitor and regulate the traffic flow onto the freeway, especially during peak period and accident conditions. The ramp metering system includes loop detectors on the mainline and along the freeway entrance and exit ramps, field controllers, traffic signal heads, special supplemental signing along the freeway entrance ramp, and central computer and software systems.

The field controller is capable of providing four specific control plans or ramp metering rate schedules on the basis of time of day or day of the week. Each control plan would provide 16 time-of-day events and can be scheduled on a day-of-week basis. The ramp metering signal poles are equipped with a red display enforcement signal oriented downstream of the traffic. In the event of a violation, the red display would flash to alert the enforcement official of the violation.

Ramp metering can be implemented in the following mode and rate selection combinations:

- local manual rate,
- remote manual rate,
- local time-of-day rate,
- remote time-of-day rate,
- local traffic-responsive mode, and
- remote traffic-responsive mode.

The central software incorporates extensive failure management features including failure reporting, logging of daily features in chronologi-

cal order, graphic display of status and control of field devices, logging of communication errors, and production of a communications analysis report. All system status displays and controls will be implemented by using a graphical user interface in a menu-driven environment.

Central Hardware and Software Systems

The central hardware and software systems designed for this project incorporate an open system architecture that would accommodate a variety of communications technologies and protocols for traffic management. The system will use proven communications and data processing technologies and can also accommodate future technologies that emerge from ongoing research and development activities. One of the objectives for using a variety of communications and data processing technologies is to master the system integration techniques and apply the expertise to full-fledged systemwide applications in the future.

The software is designed to accommodate expansion of the traffic management system on I-476 and other roadways in the region in a number of stages. The software will be developed using functional modules, each assigned to a specific task. The software will accommodate additional modules to accomplish functions that may be required by future projects.

Advanced Vehicle Detector Test Station

The advanced vehicle detector test station will include two types of mounting configurations, side-fired and overhead-mounted, for evaluating detector technologies that are not roadway-intrusive. The side-fired detectors will be mounted on a 12-meter- (40-foot-) high pole and will focus on an area of roadway that is also monitored by the existing inductive loop detectors to facilitate an accurate evaluation. The overhead mounted detectors will be mounted on an existing overpass and will focus on the portion of the roadway that is approximately 46 meters (150 feet) away from the existing inductive loop detectors.

Geographic Information System

A geographic information system is currently under development to enhance day-to-day TCC operations and to develop a comprehensive information management system. The GIS will be used to coordinate incident management operations; geocode system locations, including the equipment inventory at each location; monitor incidents; monitor maintenance activities; and develop a maintenance management information system. The GIS software will incorporate a graphical user interface and a georeferencing system.

Traffic Control Center

The traffic control center is an existing two-room facility located adjacent to the PennDOT District 6-0 building in St. Davids, Pennsylvania. The central computer and control systems for all the field elements on I-476 will be located at this center. Room 1 of the center presently houses operator workstations for closed-circuit television surveillance and the variable message sign system for the I-95 Traffic and Incident Management System. Room 2 houses communications equipment, electrical and telephone termination equipment, and the system designed to provide emergency power for all equipment for at least ten hours during power failures. The closed-circuit television workstation will be expanded and three more workstations will be added to accommodate the ramp metering system, incident detection system, and the advanced vehicle detector test station.

The operator workstations for the I-476 Traffic and Incident Management System include the following:

Closed-Circuit Television. This workstation will consist of eight 20-inch monitors arranged in a bilevel configuration and a 36-centimeter (14-inch) television monitor with a keyboard for controlling the pan, tilt, zoom, and focus functions of the camera. A videocassette recorder will also be used to record incidents.

Network Management. A personal computer in this workstation hosts the software for T-1 communications network management, closed-circuit television switcher/controller, and video encoders and decoders.

Ramp Metering and Incident Detection System. Three computers operate over an Ethernet-based local area network. Two computers will be used as operator workstations and the third as the programmers' console.

Advanced Vehicle Detector Test Station. This workstation consists of one computer operating over the Ethernet-based local area network and will be used to collect data and develop programs for evaluating the advanced vehicle detectors.

SYSTEMS EVALUATION

The I-476 TIMS project incorporates several intelligent transportation technologies that are not yet fully developed for large-scale traffic applications. These technologies should be evaluated to determine their role in future projects and to support

efficient and practical design of future systems. In addition to the technology evaluations, the I-476 TIMS will also be evaluated as a whole to determine its benefits to the users and their acceptance of the systems. The system and technology evaluations will be conducted in accordance with FHWA's Intelligent Vehicle-Highway Systems Operational Test Evaluation Guidelines.

Several specific technology evaluations are planned for this project:

- **Advanced vehicle detector test station:** Two types of advanced vehicle detection technologies will be evaluated. One technology will use video image processing and the other will use microwave radar, acoustic, or other technology that does not incorporate video image processing. The objective of the evaluation is to determine the reliability and performance of the advanced vehicle detector technology in a typical highway environment.

- **Spread spectrum radio:** This wireless communications technology does not require a Federal Communications Commission license to operate. The signal processing in the spread spectrum system tends to suppress undesired signals, thereby enabling such systems to tolerate strong interfering signals. Performance criteria that will be evaluated include fault-tolerance of the system, transmission error rate, network management, and the ability to operate during interference by external sources.

- **Wide-area detection system test:** This system monitors a length of roadway compared to the advanced vehicle detectors that provide point-based detection. The system will be evaluated for its ability to detect incidents using a combination of video image processing technology and special incident detection software algorithms.

The results of these evaluations are expected to be published in the form of comprehensive reports for distribution to interested parties. The purpose of the project evaluation is to develop an understanding of the operation of newly developed ITS technologies under real traffic conditions and to assess user benefits and acceptance of the system. The evaluation is expected to support policy development by the public sector, including PennDOT; development and marketing strategies by the private sector; and the decision to continue, modify, or suspend specific types of technology implementation.

Evaluation Methodology

After the final system acceptance tests, the project team will evaluate the I-476 TIMS. A preliminary evaluation plan addressing the measures of effective-

ness with respect to the established goals and objectives will be developed in spring 1996.

Advanced Vehicle Detector Technology

The advanced vehicle detector test station will be used to evaluate the performance of overhead mounted detectors that incorporate video processing and microwave radar technologies. This test station is designed to accommodate advanced vehicle detectors developed by several manufacturers, and is unique in the following respects:

- The performance of advanced vehicle detectors will be evaluated under various environmental conditions occurring during a typical year,

- The influence of advanced vehicle detectors on roadway aesthetics will be studied, and

- The use of the existing roadway infrastructure such as overpasses, sign structures, and light poles, and the selection of appropriate advanced vehicle detectors will be evaluated.

The reliability and accuracy of advanced vehicle detector output data will also be compared with baseline data that will be obtained by videotaping the traffic flows at the test site and analyzing a portion of the video off line. An additional evaluation approach will be to compare the performance of the advanced vehicle detectors against the inductive loop detectors. The actual vehicle speeds will be measured by driving a vehicle through the test station and comparing it to the advanced vehicle detector measurements. These tests will be conducted during different weather conditions in order to facilitate a realistic evaluation.

The evaluation plan for the advanced vehicle detector test station will address performance criteria and measures of effectiveness; data collection requirements, including factors that affect system reliability; statistical evaluation procedures; the evaluation program implementation schedule; and evaluation report requirements.

Systematic Approach to Evaluation

The system evaluation will be initiated after the contractor has completed the 12-month operations support program. During the 12-month support program, the project team will compile the maintenance activity reports and monitor operations. The team will follow a systematic approach as described in the FHWA guidelines.

Overall Concept. This phase will identify the critical goals, objectives, and milestones as outlined in FHWA's Intelligent Vehicle Highway Systems Strategic Plan and draft National Program Plan for

IVHS. The evaluation goals and objectives will address user acceptance, system benefits, system costs, performance, and transportation system impacts, including air quality.

Goals. The goals addressed in this phase will be defined in accordance with PennDOT's requirements. The responsibilities of the evaluation team will be fully identified: addressing evaluation questions and decisions, providing technical oversight, maintaining evaluation momentum, and reviewing all relevant documents. The measures of effectiveness and the evaluation approach will be identified during this phase. A detailed evaluation plan will be developed for implementation during the later phases of the project.

Outline. The evaluation team will develop an outline of the evaluation plan and address critical issues such as data to be collected for measures of effectiveness, sources of data, estimated resource requirements, data management, and schedule.

Plan. During this step a detailed evaluation plan will include individual evaluation test plans, an integrated schedule, a data management plan, evaluation quality control and quality assurance procedures, and resolution of strategic evaluation issues.

Data Collection and Analysis. During this phase the team will define the data collection procedures and will collect, reduce, and analyze the data. The

team will also address the requirements of computer facilities, software, physical facilities and other support equipment. If required, the evaluation plan will be reviewed and modified during the analysis of the data.

Presentation of Results. A format to report the evaluation plan results will include, at a minimum, the following items: purpose and duration; summary of the system configuration; conditions, instrumentation, and models; survey instruments, instruction, controls, and variable values and settings; statistical reports of collected and derived quantities; results, interpretations, and limitations; and conclusions.

After completing the evaluation program, the team will submit a final project evaluation report that documents the major findings, conclusions, and recommendations for future deployment and will be distributed to all interested agencies.

EARLY LESSONS

The construction process for the I-476 TIMS has gone smoothly. Rapid technological developments led to design changes during construction to incorporate the latest technologies and reduce costs. On projects like the I-476 TIMS, it is advisable to make provisions in the contract to allow design changes on an as-needed basis. Design review meetings also should be held throughout the construction phase to allow the project team to evaluate new technologies for project use.