

Intelligent Transportation Systems
Field Operational Test
Cross-Cutting Study

**Incident Management:
Detection, Verification,
and Traffic Management**

September 1998



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16. Abstract Incident Management: Detection, Verification and Traffic Management Cross-Cutting report summarizes and interprets findings from Intelligent Transportation Systems (ITS) Field Operational Test (FOT) projects in the field of incident management. The FOTs considered in this report include: Advanced Driver and Vehicle Advisory Navigation Concept, Alternate Bus Routing, Atlanta NAVIGATOR, Borman Expressway ATMS, Cellular Applied to Intelligent Transportation Systems Tracking and Location, During Incidents Vehicle Exit To Reduce Time, Faster And Safer Travel Through Traffic Routing And Advanced Controls, Multijurisdictional Virginia Live Aerial Video Surveillance System, San Diego Smart Call Box, TransGuide and TRANSCOM's Systems For Managing Incidents and Traffic. The FOTs discussed here involved a significant degree of partnership or teaming, often between public and private organizations. The analysis and results presented in this report are categorized as impacts, user response, technical lessons learned, institutional challenges and resolutions and cost to implement. The findings summarized from these projects will be helpful for ITS professionals to rapidly move to develop and deploy state-of-the-art incident detection, verification, and traffic management systems. This report highlights the successes and problems these tests encountered while attempting to develop the technologies and systems to support incident management.			
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EXECUTIVE SUMMARY

Traffic incidents are obstructions or restrictions to traffic flow, such as stalled vehicles, accidents, construction and maintenance activities, adverse weather conditions, or special events. Experts estimate that 65 percent of traffic congestion is caused by incidents. Incident detection, verification, and traffic management is the process of identifying, verifying, responding to, and clearing the incident and then restoring normal traffic flow. This report summarizes and interprets recent findings from Intelligent Transportation Systems (ITS) Field Operational Test (FOT) projects in the field of incident management.

Incident detection, verification, and traffic management FOTs have provided some important findings in testing technical alternatives that can be used to implement core functions rapidly and with less expense than can be achieved through conventional means. ITS technologies such as the use of vehicles as probes, wireless communications, and a variety of nonintrusive vehicle detection technologies present promise in fully deploying the intelligent transportation infrastructure. These tests have proven that several management concepts are essential to realizing the best results from the partners' investments. These concepts include allowing adequate time for evaluation, and for the complexities of systems integration and testing.

The FOTs discussed here involved a significant degree of partnership or teaming, often between public-private organizations. As with most team-focused undertakings, institutional issues have presented challenges equal to or greater than the technical issues. The greatest challenges have centered on procurement and contracting, and on the dynamics of working in a team environment. The traveling public is the ultimate beneficiary of incident management services. These tests have shown that dealing appropriately with the public is critical to achieving optimal results. Several FOTs implemented highly successful outreach programs, both assessing public needs and concerns, and

addressing the issues that arose from the public interaction.

Several technical lessons were learned from the tests. A relatively small population of probe vehicles (5 percent) is sufficient to provide adequate traffic information, if the probes are reasonably distributed in the traffic stream. Vehicle sensors located over the roadway encountered problems of undercounting when attempting to distinguish vehicles traveling at high speed and low vehicle headway or tall vehicles. Video surveillance surfaced as the best method to remotely verify incidents. Projects using Radio Frequency (RF) communications encountered some problems with interference but these problems were overcome through tuning and refining the devices. Most RF communications proved as reliable as those using wireline systems did. Diversion routes can be an effective method of managing the traffic congestion produced by an incident as long as the capacity of the diversion routes is adequate and traffic flow is controlled by dynamic signal timing adjustments to maintain service levels. The sharing of incident information among partnering agencies, particularly law enforcement, emergency services, traffic management, and transit, produced unanticipated benefits to the involved agencies. Two effective cost saving strategies emerged: reusing existing resources and avoiding cable burial costs by using wireless technology.

The findings summarized from these projects can help ITS professionals move rapidly to develop and deploy state-of-the-art incident detection, verification, and traffic management systems. This report highlights the successes and problems these tests encountered while attempting to develop the technologies and systems to support incident management.

REPORT BACKGROUND

In 1991, the U.S. Department of Transportation (USDOT) initiated a new program to address the



needs of the emerging ITS field. This program solicited and funded projects, called FOTs. The tests were sponsored and supported by several administrations of the Department, including the Federal Highway Administration (FHWA), the Federal Transit Administration (FTA), and the National Highway Traffic Safety Administration (NHTSA).

The FOTs demonstrated potentially beneficial transportation products, technologies, and approaches. The FOTs implemented these products, technologies, or approaches on a limited scale under real-world operational conditions. These tests were an interim step bridging the gap between conventional research and development (that formed the idea), and full-scale deployment (that would see widespread use of the idea). FOTs typically included a local or regional transportation agency, as well as the FHWA, as partners in the project. The partners often included private sector providers of the equipment, systems, and services interested in demonstrating their idea. The FOTs concentrated on user service areas needing a “proof of concept” in order to achieve deployment goals.

A fundamental element of each test was an independent, formal evaluation. The evaluation was designed to produce a final report that detailed the test’s purpose, methods, and findings. The evaluation aspect of the test intended to assess whether the product, technology or approach provided effective solutions at acceptable levels of cost, schedule, and technical risk.

As the sponsoring organization and a partner in many of the FOTs, the FHWA played a central role. FHWA supported the tests by providing a standardized set of evaluation guidelines and by helping coordinate and promote the relationships among test partners. The FHWA also acted as the communications clearinghouse collecting

reviewing, and disseminating information about the tests.

Among the more than 80 FOTs, several tests encompassed the same or similar areas of interest. FHWA has prepared several “cross-cutting” studies that compare or synthesize the findings of multiple tests within a particular area of interest. The purpose of this series of studies is to extract from the separate tests the common information and lessons learned that are of interest to ITS practitioners. These are lessons that could improve the testing and deployment of future applications of the subject technology.

This report is one of the series described above. It focuses on the topic of Incident Detection, Verification, and Traffic Management using ITS technologies.

INTRODUCTION

It is estimated that over half of the traffic congestion in the U.S. is caused by incidents. Incidents such as accidents, construction and maintenance activities, adverse weather conditions, parades, sporting events, tourist attractions, or other events can cause congestion by temporarily increasing demand or reducing the capacity of the transportation network. Even minor incidents, such as a disabled or abandoned vehicle on the shoulder can reduce roadway capacity and create a potential safety hazard.

The problem is growing worse. As presented in Exhibit 1, the percentage of congestion due to incidents is expected to increase to 70 percent by the year 2005. Incident related traffic congestion will cost the U.S. public over \$75 billion in the year 2005 in lost productivity assuming an average rate of \$10/hour lost due to congestion, and also results in the waste of over 8.4 billion gallons of fuel. These losses, in addition to the air quality and environmental impacts, clearly



indicate the need for immediate measures to mitigate incident occurrence and impact.

WHAT ARE INCIDENT DETECTION,

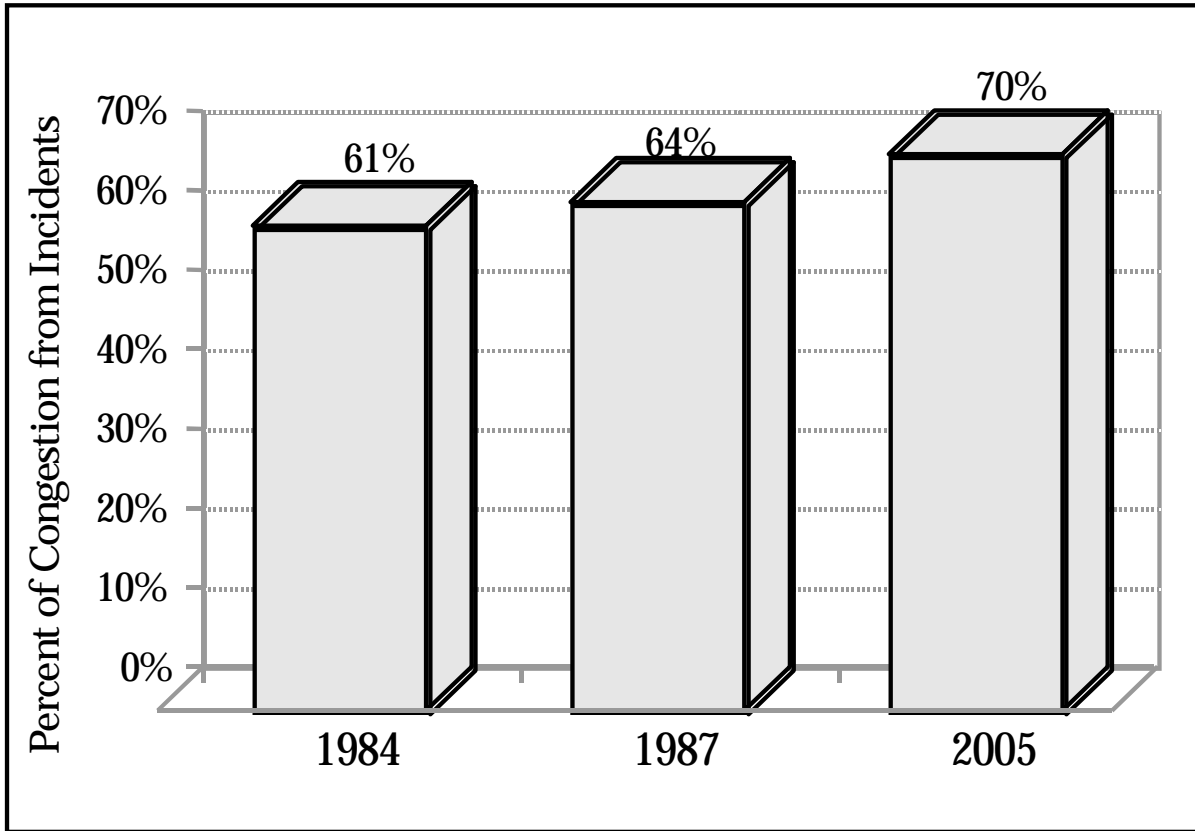


Exhibit 1: Traffic Congestion Caused by Incidents ^[Lindley 1989]

Over the past 35 years, incident management programs have been implemented in various locations throughout the U.S. as a systematic approach to minimizing the traffic congestion, air quality, economic productivity, and safety impacts of incidents. This report presents the results of nine FHWA ITS FOTs and the ITS deployment in Georgia for the 1996 Summer Olympics, and discusses the possible implications of these findings for further deployment of incident detection, verification, and traffic management services.

VERIFICATION, AND TRAFFIC MANAGEMENT?

The *National ITS Program Plan* stated that “The Incident Management user service will use advanced sensors, data processing, and communications to improve the Incident Management capabilities of transportation and public safety officials. The service will help these officials to quickly and accurately identify a variety of incidents, and to implement a set of actions to minimize the effects of those incidents on the movement of goods and people. In



addition, the service will help officials to identify or forecast hazardous weather, traffic, and facility conditions so that they can take actions in advance to prevent incidents or minimize their impacts.”

Incident management involves five major phases. They are:

- Incident Detection
- Incident Verification or Surveillance
- Incident Response
- Incident Clearance
- Queue Dissipation

As presented in Exhibit 2, these steps occur sequentially. The schematic below presents the temporal distribution of the five phases and describes the key time points during the incident management process.

Beside these five steps, on-scene traffic management and motorist information dissemination commences during the incident response phase and continues throughout the incident impact period.

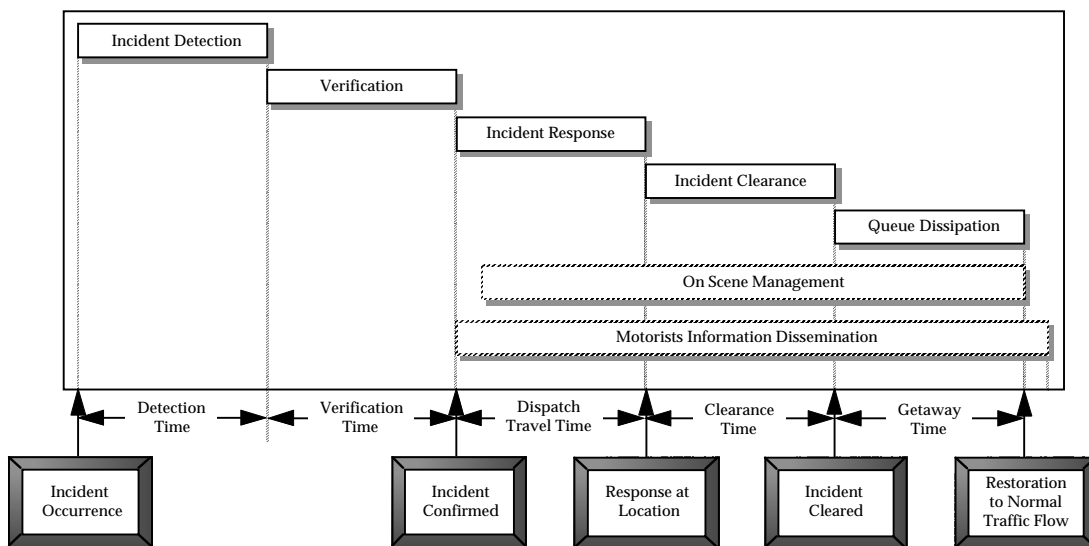
INFORMATION SOURCES

This report was prepared using material gathered as part of Booz·Allen & Hamilton’s work to provide evaluation oversight support of ITS FOTs. This material includes published and unpublished reports prepared by the test personnel and evaluators as well as information gathered in meetings and conversations with test personnel. Booz·Allen was not directly involved in the conduct of the tests. The reports prepared by the test personnel and evaluators present the findings, results, and conclusions of the tests themselves. This report interprets the results of a group of tests that have a common theme in an attempt to extract lessons that cut across the group of tests. Because it draws from the results of the tests as a group, this report may offer lessons and conclusions that are not found in the material from the individual tests.

FOTs CONSIDERED IN THIS ANALYSIS

Advance Driver and Vehicle Advisory Navigation Concept (ADVANCE)

The primary focus of the ADVANCE FOT was to address the concept of dynamic route guidance. ADVANCE utilized travel time data reported by traffic probes and loop detectors and





anecdotal incident information to provide travelers with the quickest route to their destinations in the northwest suburbs of Chicago. The ADVANCE Traffic Information Center (TIC) processed and transmitted travel time data to vehicles equipped with Mobile Navigation Assistants (MNAs), which provided route guidance and dynamic route guidance information directly to drivers through an in-vehicle mounted graphic user interface. The MNA's vehicle location system used Global Positioning Systems (GPS), RF-based differential GPS, dead reckoning, and map matching using a CD-ROM map database.

ADVANCE utilized vehicles as probes for monitoring traffic conditions on freeways and arterials in a large geographic area (incident detection), and provided diversionary routing to vehicles carrying the onboard vehicle navigation unit (incident management). ADVANCE operations have been completed.

Alternate Bus Routing (ABR)

The (New Jersey) ABR FOT combines information from vehicle probes, conventional vehicle detection technologies, and anecdotal reports to determine optimal routing for buses within a defined corridor. The system applies a travel time algorithm to recommend a preferred route for each bus, and provides the traffic operations operator-approved route recommendation to the vehicle operator via an onboard annunciator.

The ABR test addresses several areas directly impacting incident management. It serves as an additional test of the ability of vehicle probes to provide traffic condition information. It integrates this probe information with information from conventional vehicle detectors. It tests an algorithm that recommends diversion routing, which is a significant method of reducing the impact of an existing incident, and

determines the overall travel time impact of vehicles taking the diversion route.

ABR has completed its first phase, and work is underway on a final evaluation report. The agencies have decided not to proceed with the second project phase.

Atlanta NAVIGATOR

The Atlanta NAVIGATOR ITS deployment (not an FOT) is a massive integrated Advanced Traffic Management Systems (ATMS)-Advanced Traveler Information Systems (ATIS) deployment in the greater Atlanta metropolitan region. The system includes several incident management features including real-time traffic parameter data collection, congestion monitoring, automatic and manual incident detection, freeway safety patrols, Closed Circuit Television (CCTV) cameras, changeable message signs, highway advisory radio and a host of interconnected ATIS features to disseminate traveler information. In addition to managing traffic conditions during normal Atlanta travel periods, the system was called upon to manage the special traffic conditions brought about by the 1996 Summer Olympic Games.

The system continues in operation, with additional equipment installation, software improvements, and additional integration planned or underway.

Borman Expressway ATMS

This FOT developed and evaluated the use of ATMS along a three-mile section of the Borman Expressway in northern Indiana. This test was Phase I of a project to establish an ATMS for the entire 16-mile Expressway. In Phase I, the Indiana Department of Transportation evaluated the use and viability of a variety of above-road



vehicle sensing technologies and an advanced communications system.

Cellular Applied to Intelligent Transportation Systems Tracking and Location (CAPITAL)

The purpose of the FOT was to demonstrate the ability to locate and monitor cellular phone equipped vehicles, to gather data about traffic flow, volume, speed, and detection of probable incidents. CAPITAL tested, on Washington, DC, metropolitan area freeways and arterials, a method of obtaining real time traffic data which could be implemented rapidly and with moderate cost of operation and maintenance when compared to conventional vehicle detection technologies. CAPITAL operations have been completed.

During Incidents Vehicles Exit to Reduce Time (DIVERT)

The purpose of the DIVERT ITS FOT is to make effective use of parallel arterials adjacent to a congested and incident-prone segment of interstate highway in St. Paul, Minnesota. DIVERT provides an opportunity to analyze the utility of diversion routing over arterials, and of the impact of diversion on local traffic flow. The system provides demand-responsive signal timing along the arterials to accommodate the additional demand, and monitors both freeway and arterial traffic conditions with detection and video surveillance equipment. DIVERT is currently in operation, with data collection ongoing. DIVERT operations are scheduled for completion in the second half of 1998.

Faster and Safer Travel Through Traffic Routing and Advanced Controls (FAST-TRAC)

FAST-TRAC implemented a real time, adaptive traffic control system integrated with a traveler

information system using in-vehicle display units in Oakland County, Michigan. These units provide real time route guidance information from a central routing system that utilizes vehicle location information as traffic probe data. The FAST-TRAC system also uses video image detection systems to provide vehicle detection at intersection.

FAST-TRAC tested a relatively new vehicle detection technology — video image detection. It also utilized vehicles as probes to determine travel conditions and it had the capability to provide diversion routing to vehicles carrying the onboard traveler information device. FAST-TRAC is now assessing the challenges of integrating dissimilar systems into an operating Traffic Information Management System. The SCATS and AUTOSCOPE systems implemented as part of FAST-TRAC continue in operation and represent the core of Oakland County's transportation management infrastructure. Data collection, analysis, and preparation of a case study are ongoing.

Multijurisdictional Live Aerial Video Surveillance System – Virginia

The Multijurisdictional Live Aerial Video Surveillance FOT assessed the effectiveness and limitations of traffic surveillance from a helicopter. This concept could potentially provide video surveillance over a large geographic area with a low initial cost, and without significant communications infrastructure. The surveillance resource could be used to gather traffic condition information over a planned route, and could also be targeted at known problem areas and existing incident sites. The video received from the system could be used to identify and resolve recurring problems, for traffic studies, to document conditions for presentation to officials, and in areas not warranting full time video surveillance infrastructure. The test also demonstrated an approach where multiple agencies benefited



from one another's investments in both capital resources and in operations and maintenance of those resources.

The project outfitted an existing police helicopter with a video camera and microwave transmission system. The helicopter flew 90 minutes during AM and PM peaks, providing video images to Virginia Department of Transportation (VDOT), law enforcement, and emergency services, via links to the Fairfax County Public Safety Communications Center. A mobile law enforcement van was also able to receive video directly from the helicopter.

The FOT has been completed and the system continues to operate as part of the VDOT's Northern Virginia Transportation Management System.

San Diego Smart Call Box

The purpose of the San Diego Smart Call Box FOT was to demonstrate the possibility of using existing roadside call boxes as communication links to additional transportation management infrastructure, such as vehicle detectors, video cameras, Variable Message Signs (VMS), and weather information stations. Thus, Smart Call Box tested a technology that supports the deployment of incident detection, verification, and traffic management resources.

Successful application of this project's approach would allow implementation of transportation management infrastructure more rapidly and at significantly reduced cost, by eliminating the need for fixed communication infrastructure to support the roadside equipment. The San Diego Smart Call Box FOT report of final results is presently in preparation and review. CalTrans is pursuing a small-scale pilot deployment of some Smart Call Box functions in order to further test and refine the system.

TransGuide

TransGuide is the ITS deployment in the greater San Antonio, Texas area. In conjunction with the implementation of the first phase of the TransGuide ATMS, an ITS FOT was initiated whose purpose was to provide a detailed explanation of the project technology design decisions. This included the selection of a fully redundant fiber optic communications network, all-digital communications, and high magnification video cameras. The operational test also documented how the system met strenuous objectives for the time to detect, verify, and respond to freeway incidents.

TransGuide demonstrated the ability to apply advanced technology in a conventional ATMS architecture to achieve significant improvements in safety based on rapid detection, verification, and response to freeway incidents. The system was implemented in a multi-agency cooperative environment, and was sized for expansion to provide regionwide intelligent transportation infrastructure.

The TransGuide ITS FOT examined issues within the context of the first phase of the deployment of the TransGuide advanced transportation management system, which covered the interstates within San Antonio's central business district. Additional centerline miles of TransGuide are being implemented. Simultaneously, modifications to and expansions of system functionality have been implemented.

TransGuide is also one of the first four ITS Metropolitan Model Deployment Initiative sites. This expansion of the FOT will evaluate system performance across a larger area, along the northern crest of San Antonio's beltway.

TRANSCOM's Systems For Managing Incidents and Traffic (TRANSMIT)



The purpose of the TRANSMIT FOT was to evaluate the ability to use existing vehicles carrying electronic toll collection tags as traffic probes as they approached the New York City area. The travel times of these vehicles could be analyzed in order to reliably detect incidents and to monitor traffic conditions.

The TRANSMIT approach of expanding upon the use of existing infrastructure could provide a moderate cost method for rapidly expanding the ability to monitor traffic conditions and to identify incidents on both freeways and arterials in a large geographic area.

Following measurement of initial results, the agencies involved in TRANSMIT are implementing the system on additional roadways in the New York/New Jersey area. The initial project area continues to be operated as part of TRANSCOM's transportation management infrastructure.

FINDINGS

This section presents the comparison of the similarities and differences of these tests and an interpretation of the results. Findings are organized into five categories:

- **Impacts**—whether the results of the tests caused changes
- **User Response**—how test participants reacted
- **Technical Lessons Learned**—conclusions about the ease of use, applicability, transferability, and safety of the tested technologies
- **Institutional Challenges and Resolutions**—conclusions about the

relationships among the test partners, institutional barriers, and legal issues

- **Cost To Implement**—how the costs may affect the potential development and deployment of the technologies

IMPACTS

The nine ITS FOTs involving incident management issues have primarily focused on six major goals:

- Reducing the cost to deploy (and then operate and maintain) the infrastructure necessary to monitor traffic conditions and to detect, verify, and respond to incidents
- Reducing the time necessary to deploy or expand deployment of intelligent transportation infrastructure
- Exploring opportunities for agencies to work together to implement intelligent transportation infrastructure and then optimize coordinated incident detection, verification, and response activity
- Effectively utilizing freeways and arterials in a mutually supportive manner to mitigate the effects of incident-related congestion
- Documenting the impacts that incident management systems have on congestion, safety, and air quality, and documenting public acceptance of and compliance with traveler information delivered by incident management systems
- Exploring the effectiveness of several new technologies for the basic ATMS functions that may provide additional functionality (e.g., vehicle classification) beyond those needed by an ATMS or may avoid problems such as unreliability, pavement intrusion,



and traffic disruption which are associated with conventional solutions

Findings in each of these areas have provided critical information necessary to determine if the new approaches are practical for widespread deployment. Several tests also identified problems that are likely to occur with early deployments of the new technologies or approaches, and examined possible solutions. Several tests generated conclusions on benefits of various incident management approaches. These conclusions are summarized below in four categories: incident detection, incident verification, traffic management, and the technologies that support them.

Incident Detection

Vehicles As Probes

Several tests have proven the ability of vehicles to act as probes, providing sufficiently accurate and timely information on traffic conditions (typically link travel times) and likely incidents (typically derived from comparing actual link travel times to statistical norms) for use in both transportation management and traveler information. Vehicle probe data has been generated via location information derived from onboard sensors, from vehicle location sensed by an infrastructure-based vehicle navigation system, from detecting the RF toll tags carried by vehicles, and from interaction between cellular telephones used by vehicle passengers and the cellular phone roadside infrastructure. Over 25 percent of the incidents on the New York State (NYS) Thruway during TRANSMIT's test period were detected first by TRANSMIT, with half of these detected at least 11 minutes earlier than by conventional vehicle detectors. In situations where such conventional detection systems detected incidents first, nearly 65 percent were detected less than 10 minutes before they were noted by TRANSMIT. Of

equal importance, TRANSMIT experienced very low adjusted false alarm rates.

Several tests have successfully integrated probe-derived link travel time data with point or average speed readings from conventional vehicle sensors. This integration demonstrates the ability to expand upon existing conventional vehicle detection infrastructure with less infrastructure-intensive traffic monitoring. The New Jersey Alternate Bus system found acceptable results weighting probe data twice as heavily as conventional detector data in its algorithm.

The net effect of these demonstrations is that several other metropolitan areas, such as San Antonio and Houston, are now using vehicle probes as an accepted method for rapidly and inexpensively extending the "reach" of their conventional traffic monitoring environment. Similarly, TRANSMIT is expanding its coverage area significantly using vehicle probes.

Incident Verification

Relatively few tests have addressed innovation in video surveillance. Virginia's Live Aerial Video test addressed the challenge of developing less infrastructure-intensive incident verification mechanisms, by using an aerial video platform. Performance of the aerial video approach proved in some ways superior to fixed video surveillance because aerial video:

- Quickly scans overall incident scene
- Quickly detects secondary incidents
- Can provide specific details via request to pilot
- Is useful for monitoring special events that cover a large area over an extended period



- Is useful for a variety of objectives, beyond simple incident verification, such as traffic studies or corridor analyses

The TransGuide FOT investigated a very different approach to conventional video surveillance: the use of very high quality video to improve the agencies' ability to respond effectively to incidents. TransGuide implemented video cameras at one-mile intervals. The cameras were near-broadcast quality, with an unusually high (48:1) magnification lensing, on pan/tilt mountings. Through use of TransGuide's high-bandwidth fiber optic communications network, the video images were compressed only minimally for transmission to the traffic operations center. The objective of this approach was for the traffic systems operator to be able to better identify the resources required to manage the incident, so that they could be immediately dispatched. Although no statistical results are available, tests confirmed excellent performance in areas such as nighttime visibility and identification of support needs at the incident site, in comparison to a variety of other camera technologies, including near-infrared, black/white, lower cost, and lower magnification cameras. TransGuide operations personnel report that the system has provided excellent results under a wide range of lighting and weather conditions, and that they feel that their understanding of incidents is well supported by the high quality video images.

Experience in Maryland with lower resolution video images has also proven to be satisfactory for incident verifications, at lower cost.

Incident Management

Trials have verified the potential benefits of active incident management to the traveling public. Although actual travel time-savings are difficult to isolate and are often "contaminated" by the benefits of other improvements made in a single project, safety improvements such as

reductions in secondary incidents, total number of incidents, and incident response time were clearly proven. TransGuide experienced a 15 percent reduction in injury related accident rates, and projected that the improvement would grow to 21 percent based on trends during the test period. It also achieved an overall reduction in time to detect, verify, and respond to incidents of 20 percent. The test achieved response times below 20 minutes for major and minor incidents, as measured by the San Antonio Police Department.

The willingness of motorists to respond to incident-related travel information from both wide area (VMS, Highway Advisory Radio -- HAR) and in-vehicle sources was confirmed by several tests. In its first year of operation, TransGuide noted a significant increase in the portion of motorists who had noticed and complied with the VMS messages. This portion rose from 33 percent to 80 percent. Further, the number of San Antonio motorists stating that they used alternate routes during incidents increased from 45 percent to 71 percent.

In systems with well prepared diversion routes, the primary benefits from incident management seem to accrue not from diversion but from rapid detection, effective response, and timely clearance of incidents. Although TransGuide included provisions to modify signal timing on the arterial "frontage" roads adjacent to the interstates, this capability was seldom used. Although not statistically verified, anecdotal evidence such as from TransGuide, and an earlier implementation in Fort Worth indicates that directional lane control devices can be an effective support to incident management, assisting in directing travelers into available lanes and away from incidents and debris, well in advance of the danger zone.

Not surprisingly, the effectiveness of diversion routes is highly dependent upon the route's condition. In order to assure that the diversion



route is capable of effectively supporting its role, most tests monitored the diversion route. They also took steps such as changing signal timing and adding temporary signage to improve the route's capacity to carry the temporary additional load, and to assure that motorists understood how to proceed along the route and how and where to re-enter the primary roadway. The DIVERT test provides an excellent example. DIVERT not only performed initial capacity analysis on the diversion routes for both peak and off-peak periods, but also studied ramp capacity. The system monitored several measures of effectiveness while in the diversion mode, and adjusted signal timing when capacity was available to keep the level of service from dropping. In the future, the city also plans to implement video surveillance along the diversion routes. The ABR system also monitors and compares the available routes, and only recommends diversion if the alternate route is better than the primary route by a predetermined threshold.

An additional benefit from incident management achieved by several tests accrued from sharing incident information between agencies. The most common relationships were between law enforcement, emergency services, traffic management, traffic control, and transit. In some cases this sharing was achieved by electronically transmitting the information between separate locations, by collocating personnel from different agencies in a single Transportation Management Center (TMC), or by other means such as voice communications, pager, or fax. TransGuide furnishes one example of how this works. As the sensor network detects a suspected incident, a TxDOT shift supervisor is notified. If the supervisor considers it to be worthy of verification, the incident alarm occurs not only at traffic operations, but also at the San Antonio Police Department officer station in the control center. Personnel from Via Metropolitan Transit, San Antonio's transit property, are also onsite within

the control center, and have access to the information over identical workstations. A remote workstation connection has also been provided to Via's downtown headquarters. In another test, the Virginia Live Aerial Video demonstration shares video images between VDOT and local law enforcement and emergency services units. In Atlanta, agencies worked closely, both in instances where personnel were collocated in the TMC and where information was distributed to the city and county traffic control centers.

In all cases, the incident management process kept "the person in the loop," never allowing the system to deliver critical traveler information without approval of an experienced individual. TransGuide, NAVIGATOR, DIVERT, and ABR system are highly automated, but none allows its system to take action without human approval beforehand. These projects achieved maximum cost savings, however, by automating the detection, verification, and solution development to the greatest extent possible.

Technologies Supporting Incident Detection, Verification, and Traffic Management

The most common solution found to reduce the cost of incident management system implementation was to reuse existing resources. Since communication was often half of the total cost of deploying an incident management system, using existing communication resources would be a significant cost saving strategy. A second cost saving strategy would be avoiding the intensive investment of cable burial by using wireless communication. Some Smart Call Box sites avoided both the cost of communication cable burial through the use of RF communications. They also avoided the cost of power cable burial by using low-power equipment and solar power receivers with battery storage. This arrangement can, however,



present problems in applications with constant demand (i.e., 30-second polling of detectors), at night, or in inclement weather situations. A second alternative, contracting for communications services (“leased lines”) can also provide the required connectivity with significantly lower capital cost, but will incur an on-going stream of payments for the duration of the service.

A related lesson is that, when making the communication investment, there can be a great long term benefit to sizing the infrastructure to handle the eventual bandwidth demand.

Experiences with incorporating new technologies into the intelligent transportation infrastructure have been mixed. As many tests attempted to quickly implement and integrate multiple technologies with limited funds, it should not be surprising that problems arose with the technologies. Most technologies demonstrated in the tests proved adequately successful, or could be made so with further testing, debugging, and integration.

USER RESPONSE

All tests evaluating user response have arrived at a uniform conclusion that travelers will act based upon information from a trusted and well-understood system that provides information of value. TransGuide’s survey of motorist reaction to the information demonstrated a high level of acceptance of the system (80 percent followed its instructions), and a significant level of appreciation (71 percent felt they saved time) for the benefits they derived from it. No test has quantified isolated travel time benefits from incident management information alone, but motorists clearly felt that they derived an appreciable benefit from acting on the information, even in situations where information was only available en-route, such as in TransGuide Phase I, and where diversionary routing was not utilized. Acceptance data was excellent from TransGuide’s implementation of

directional lane control signals, although the impact of these devices could not be isolated from the impact of the remainder of the incident management system.

FAST-TRAC experienced negative public perception due to problems with project/system image management. TransGuide attributes part of its success to a significant investment in outreach; DIVERT also executed an extensive outreach program, and identified project objectives in both travel behavior and user acceptance categories.

Concerns over privacy, including video surveillance by “big brother,” and tracking of movement of individuals by cellular phone or electronic toll tag, continue to arise periodically, but much has been done to assuage such fears. CAPITAL directly addressed these issues successfully through a planned media program working with cellular communications providers. Privacy policies, such as that developed by ITS America in cooperation with USDOT and many of its member agencies have made clear the issues related to privacy when technologies being used in incident management systems have the potential for violation of privacy. Specific measures within a project such as assignment of random numbers to toll tag transaction records when they are being used only for monitoring traffic flow and components in the outreach program have been shown to calm fears of motorists and area residents.

Although concerns often arise over the impact of diverting traffic from major roadways onto surface streets, no test has yet demonstrated any substantial negative impact from such diversions. Projects that included planned diversions carefully prepared incident management solutions, such as TransGuide’s “scenarios” which were tailored to each potential incident type and location. Both DIVERT and TransGuide developed these solutions in consensus with agencies responsible for



transportation throughout the affected area. This careful preparation has thus far prevented the floods of high-speed traffic through residential areas that were once feared. Other key components of responsibly planning to prevent such negative impact have been:

- Careful traffic engineering analysis of the alternate route
- Identification and implementation of possible improvements to the diversion route (such as signage, lane marking, and geometrics)
- Effective coordination of the diversion route's traffic control system to accommodate the increased volume generated when it is in use as a diversion route.

Together, these and other measures have prevented situations that could have created a significant public outcry against the use of diversion routing as a component in incident management.

TECHNICAL LESSONS LEARNED

Infrastructure Based Detection

TransGuide implemented a relatively conventional automated incident detection system, using pairs of inductive loop vehicle detectors in each lane at ½-mile intervals. Properly installed loops are typically both economical and reliable in the south Texas road environment. The Texas Department of Transportation (TxDOT) initially developed and implemented an algorithm based only on vehicle speeds. Although this algorithm worked well at reasonable vehicle flow rates, it produced erratic results late at night with few vehicles traveling the roadways. An alternative algorithm was developed, tuned, and implemented for these

periods. In later extensions of the regional deployment, passive acoustic detectors have been added to the network, and have also functioned adequately. TxDOT reports confidence that the system consistently meets their target of detecting incidents within two minutes of occurrence.

The Borman (Indiana) Expressway FOT implemented 5 sensor technologies, with a total of 6 different types of devices, including 12 inductive loops. The sensor suite included microwave continuous beam/Doppler shift, microwave frequency modulated/continuous wave, active ultrasonic, active infrared, and passive infrared. Both overhead and side-mounted configurations were implemented. Conventional inductive loops were also installed for comparison. The loops exhibited poor reliability and were subject to construction losses.

The Borman test sought detectors that would provide speed, volume, and occupancy information. These parameters are the core components of most computerized incident detection algorithms. In addition, the test evaluated one detector that provided vehicle classification. None of the detectors as tested met all of the test's performance criteria. The best detector (as installed during the test) missed 10 percent-15 percent of the vehicles. Primary problems in sensor performance were attributed to low vehicle headway and high vehicle speeds, which typically resulted in undercounting. In particular, tall vehicles presented problems for overhead sensors. Many sensor reliability problems were due to fixable installation difficulties. The test concluded that, in each deployment, sensor adequacy should be evaluated based on the needs of chosen algorithm. Regarding installation, the test concluded that if overhead sensors are implemented, a procedure should be developed to adjust, tune, and repair the sensors that reduces the difficulty, cost, and danger of such



work, and that eliminates the need for lane closures.

The Atlanta NAVIGATOR experience provides lessons in incident detection. NAVIGATOR implemented a massive traffic detection infrastructure – over 315 Autoscope video image detection cameras, over 50-radar speed sensors, and 67 CCTV cameras with pan-zoom-tilt capability. During the 1996 Summer Olympic Games, however, incidents were primarily detected through manual efforts augmented by the ITS resources, but without a working algorithm. Manual detection was necessary because the computerized automatic incident detection algorithm was not yet operational in time for the Olympic Games. Sixty percent of the incidents were detected through manual monitoring of CCTV cameras, by Metro Network primarily using aerial surveillance, by the HERO traffic safety patrols, and by *DOT toll free cellular calls. This mix of methods proved effective in rapidly detecting incidents, although it was labor intensive and therefore expensive, and human factors concerns exist regarding the constant scanning of banks of monitors by control center personnel.

The computerized incident detection system was brought online in late 1996, using two incident detection algorithms. However, due to data accuracy problems at a few Autoscopes causing high levels of false alarms at these locations, the automated incident detection system was not used until the end of the year.

Several of the key technical lessons learned from these projects relate to the use of vehicle probes for gathering traffic condition data and locating incidents. A key early finding was that relatively small populations of probes (5 percent), if reasonably distributed over time, are sufficient to generate traffic information adequate for effective traffic management. Only when the population of probes becomes exceedingly small or traffic flow sparse does accurate information

become a problem. CAPITAL noted this problem on arterials in its test area, and during late PM/early AM hours. The level of probes necessary seems greater if the number of reader stations is fewer (greater distances apart) and if probes are involved in stop-and-go traffic such as on signalized arterials.

Data regarding the time to detect incidents with probes is still thin, but TRANSMIT results indicated that probes may perform as well as, and in some instances better than, conventional vehicle detector-based incident management systems.

Adequate integration of probe data with data from vehicle detectors has been achieved with fairly simple algorithms. ABR added 1/3 probe data to 2/3 detector data. Not much detailed research has been performed on the algorithms, and it is likely that improved results will be obtained from refined algorithms.

TRANSMIT FOT logged detection rates ranging from 67 percent to 95 percent. The false alarm rate varied from 0 to 3.4 times per 100,000 times the algorithm was polled. These results put the TRANSMIT algorithm's performance comparable in detection rates, and superior in false alarm rates to the California algorithm, the High Occupancy Algorithm (HIOCC), and the double exponential smoothing model.

The CAPITAL project tested an alternate probe technology, tracking of vehicles via signals from cellular telephones. Although troubled by rapidly changing cellular technology, at its completion CAPITAL was able to locate probe vehicles within a range of 24 to 185 meters, and was able to detect 93 percent of the incidents logged by local traffic management agencies. The test, however, experienced an 80 percent false alarm rate. The system was comparable in cost to loop-based systems, at \$25,000 per mile for implementation.



None of the tests has identified any better way than video surveillance to verify incidents and gather the detailed information necessary for increased effectiveness in incident response. Aerial video surveillance worked quite well in Virginia and Maryland, although no formal evaluation was performed in Maryland. Both projects have continued using video surveillance after the testing concluded. Technical challenges in aerial video were primarily in antenna positioning and transmission path. Virginia achieved best results after adjusting antenna positioning at both transmitting and receiving ends, and by adding appropriate signal filtering.

Other tests involving airpath communication (Smart Call Box and Borman Expressway ATMS) have encountered antenna aiming and transmission path problems, as well as problems with frequency utilization. Frequency problems are most common in industrially active urban areas, and may be overcome by using systems that offer several frequencies. None of the tests encountered any transmission problems that did not seem possible to overcome with thorough tuning and refinement. The Borman ATMS project found that the primary interference was from other project radios. Most tests of RF communications, once fully debugged and operational, have been at least as reliable as those using wireline communications, and without the exposure to disruption from construction activity. Borman found its fixed site links had negligible error rates, and were reliable. Communication with mobile platforms, however, varied due to conditions and movement. In general, though, these tests were not undertaken until careful analysis of the communications environment had been performed to avoid any major communication conflicts and disturbances.

One finding regarding the incident management process has been that incident management works best if the incident is monitored and the response adjusted after an initial solution has

been initiated. Incidents appear to be dynamic, as are motorists' responses to them. Thus the most effective response needs to also be appropriately dynamic. Both TransGuide and DIVERT implemented this approach.

Many tests have experienced the technical challenges of system testing and integration. Smart Call Box encountered particular problems in using commercial products with off-the-shelf software for new purposes. NAVIGATOR continued bringing new systems online throughout the Summer Olympics, and lost some communication links due to system conflicts during the Games. Other tests have encountered a variety of "bugs" in both commercial and custom software. Incident management systems depend upon many thousands of lines of software code, often significantly customized to the local conditions and operations concept. In systems implementing new approaches dependent upon algorithms, adequate time should be allowed for ongoing refinement of the algorithm(s). Multiple algorithms may be necessary in order to deal with different road and traffic conditions (peak/off-peak, weekday/weekend), as was the case in TransGuide.

Equally challenging has been making the many different devices involved in a comprehensive incident management system work together as planned. Key lessons have been:

- Retain properly qualified and experienced organizations for both software and systems integration.
- Develop and execute proper quality assurance and testing programs.
- Implement careful documentation and configuration management programs.



- Allow adequate time and budget for the unforeseen challenges that are likely to arise in this key program phase.

A related finding has been that system repair and refinement, as with scientific experimentation, suffers if too many changes are made between tests. Several tests made multiple modifications and adjustments between tests of operational condition, which resulted in greater confusion and no improvement in operational status. DIVERT's geometric improvements, made at the same time as the system was implemented, appear to have significantly reduced the number of situations in which diversion will be needed, although there were fewer than a dozen during the test period, making it difficult to determine the effectiveness of the diversion system.

INSTITUTIONAL CHALLENGES AND RESOLUTIONS

A wide variety of institutional issues have arisen in the incident detection, verification, and traffic management ITS FOTs. These same issues are commonly found in larger scale system implementations, and the solutions explored in the FOT program may be useful to those programs.

A primary area of difficulty has been procurement and contracting. As most FOTs have involved some portion of private sector funding, issues have included:

- Privacy of sensitive corporate information

• Int

• Rig
pul

• Va

<i>Cost Item Description</i>	TRANSMIT (AVI Based)	ILDS	VIDS	MRDS
Capital Cost:				
Hardware Costs	\$14,700	\$4,100	\$24,500	\$26,500
Installation Costs	\$21,700	\$50,560	\$45,100	\$25,200
Maintenance Costs/Year	\$2,900	\$7,950	\$3,300	\$2,900
Operations Costs/Year	\$2,040	\$2,040	\$2,040	\$2,040

Table 1: Comparative Costs Per Detection Site (Six lane)

[after NJIT, 1997]

Since many ITS projects include public-private partnerships such as are common in FOTs, FOT experience with partnerships may also be valuable. In more than one case, the definition of "partnership" between the public-private sector participants has been confusing, with project partners unsure how a "partnership" differed from a more conventional contracting arrangement. Unfortunately, no universal solutions have emerged, primarily because each situation differs, particularly with regard to the regulations of the involved agencies.

Partnership issues have become further complicated in situations where multiple agencies have teamed. Such teaming has the potential to create a situation where, not only are partners unaware of one another's requirements, but also where funding may flow from one institution, through a second, to the final user institution, as was the case in FAST-TRAC. This creates a cascade of possibly even conflicting requirements, and can slow the project approval process to a point where any meaningful progress is difficult.

A complicating result of slow project progress is the impact of ongoing technological advancement. Several projects have found themselves implementing devices or approaches which, when the system was conceived, were well ahead of their time, but which were possibly commonplace or even outmoded when the work was completed. CAPITAL encountered major technical challenges due to technical evolution that altered some of the assumptions on which it was based.



Challenges continue during project implementation. Extended review processes, differences in the partners' goals, and slow consensus-based decision making can add to the difficulty of moving the project forward. Assurance of continued funding for multi-year projects has increased the level of risk experienced by both partners and the projects themselves even once work is well underway.

A core message from every project has been that a thorough and effective communication program between the partners in the project can achieve wonders in supporting project advancement. Key elements in such communication programs have included:

- A thorough knowledge of each partner's roles and responsibilities
- Understanding each partner's capabilities/limitations
- Managing expectations

The formal partnering process, pioneered by the U.S. Army Corps of Engineers, was viewed in TransGuide as having resulted in saving TxDOT millions of dollars by project completion.

Another institutional issue that is related to working in a "team" environment is dealing with outside organizations. FAST-TRAC experienced the challenge of determining who officially spoke (primarily to the media) for the project, and to what extent other partners could interact with the media.

COST TO IMPLEMENT

The major costs associated with incident detection include the capital costs of traffic detection and surveillance deployment and system installation, the operation and maintenance cost, and the system operations

costs. Table 1 presents comparative costs for four incident detection systems – TRANSMIT using a Vehicle Probe-Based System, Inductive Loop Detection System (ILDS), Video Image Detection System (VIDS) and Microwave Radar Detection System (MRDS).

The TRANSMIT system is considerably cheaper than the other three incident detection systems. While the operations costs are the same for all, TRANSMIT deployment and maintenance costs are equal to or lower than the other three making it considerably less expensive overall. The TRANSMIT hardware costs include all hardware required to read and process Electronic Toll and Traffic Management (ETTM) tag data for estimating travel times. The incident detection computer costs are also included. The calculation assumes that thousands of users already have ETTM toll tags in their vehicles – the costs of outfitting these vehicles with tags (at approximately \$50 to \$100 per vehicle) is not included as part of the TRANSMIT capital costs. This reduces the system cost since the system uses existing infrastructure (RF tags) already deployed for a different need – electronic tolling.

SUMMARY

The results of the ITS projects summarized here show that the tools and technology for incident detection, verification, and traffic management can provide significant benefits to user organizations. These tools and technology have been shown to be practical and efficient. The combination of technologies has already had a positive impact on the metropolitan areas in which they have been implemented. The examination of user reaction to the technologies has shown that they will change their driving patterns if they trust and understand the source of incident information. These projects have highlighted several technical lessons that can benefit organizations that are in the process of developing and implementing similar system.



The projects have shown that institutional issues remain one of the most significant challenges; also that these issues can be overcome when the partners work together. The limited information about implementation costs indicates that the new technologies can be substantially less expensive than existing technologies.

This report was based on the results of incident management operational tests in different stages of completion, some completed, others still in progress. Considering the results from these projects, it is reasonable to expect that the character of the next generation of incident management systems is likely to demonstrate additional benefits.



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