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Intelligent Transportation Systems[1]

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[1]*Note:* This document contains very substantial portions of text, largely unchanged, from references 1, 2, 32, 38, 41, and 46.

65.1 Introduction

Surface transportation systems in the United States today face a number of significant challenges. Congestion and safety continue to present serious problems in spite of the nation's superb roadway systems. Congestion imposes an exorbitant cost on productivity, costing the nation an estimated $40 billion per year. Vehicle crashes cause another $150 billion burden to the economy and result in the loss of 40,000 lives annually. Inefficient surface transportation, whether in privately owned vehicles, commercial motor carriers, or public transit vehicles, constitutes a burden on the nation's quality of life through wasted energy, increased emissions, and serious threats to public safety [41]. In addition, it directly impacts national economic growth and competitiveness.

Over the last two decades, demand for mobility has continued to increase, but the available capacity of the roadway system is nearly exhausted. Vehicle travel has increased 70%, while road capacity has increased only slightly more than 1% [47].

Except for fine-tuning and relatively modest additions, the road system cannot be expanded in many areas. The only means left for increasing available travel capacity is to use the available capacity more effectively, e.g., redirect traffic to avoid congestion, provide assistance to drivers and other travelers on planning and following optimal routes, increase the reliability of and access to public transportation, and refocus safety efforts on accident avoidance rather than merely minimizing the consequences of accidents [1].

Responding to this need, Intelligent Transportation Systems (ITS) is the integrated application of well-established technologies in advanced information processing and communications, sensing, control, electronics, and computer hardware and software to improve surface transportation performance, both in the vehicle and on the highway [1,2,32].

This simple definition underlies what has been a substantial change in surface transportation in the United States and around the world. Development of ITS was motivated by the increased difficulty — social, political, and economic — of expanding transportation capacity through conventional infrastructure building. ITS represents an effort to harness the capabilities of advanced technologies to improve transportation on many levels. ITS is intended to reduce congestion, enhance safety, mitigate the environmental impacts of transportation systems, enhance energy performance, and improve productivity [32].

Intelligent Transportation Systems, formerly Intelligent Vehicle–Highway Systems (IVHS), offers technology-based solutions to the compelling challenges confronting the nation's surface transportation systems while concurrently establishing the basis for dealing with future demands through a strategic, intermodal view of transportation. ITS applications offer proven and emerging technologies in fields such as data processing, communications, control, navigation, electronics, and the supporting hardware and software systems capable of addressing transportation challenges. Although ITS technology applications alone cannot completely satisfy growing transportation needs, they provide the means to revise current approaches to problem solving, and they improve the efficiency and effectiveness of existing systems. When deployed and integrated effectively, ITS technologies will enable the surface transportation system to operate as multimodal, multijurisdictional entities providing meaningful benefits, including more efficient use of infrastructure and energy resources, complemented by measurable improvements in safety, mobility, productivity, and accessibility [41].

Some of the effects that ITS could have in transportation operations, safety, and productivity are described next.

65.2 Role of ITS in Tomorrow's Transportation Systems

Operations

The essence of ITS as it relates to transportation operations is the improved ability to manage transportation services as a result of the availability of accurate, real-time information and to greatly enhance control of traffic flow and individual vehicles. With ITS, decisions that individuals make as to time, mode, and route choices can be influenced by information that currently is not available when it is needed or is incomplete, inconvenient, or inaccurate. For example, ITS technology would enable operators to detect incidents more quickly; to provide information immediately to the public on where the incident is located, its severity, its effect on traffic flow, and its expected duration; to change traffic controls to accommodate changes in flow brought about by the incident; and to provide suggestions on better routes and information on alternative means of transportation [2].

The availability of this information would also enable the development of new transportation control strategies. For example, to obtain recommended routing information, drivers will have to specify their origins and destinations. Knowledge of origin and destination information in real time will enable the development of traffic assignment models that will be able to anticipate when and where congestion will occur (origins and destinations can also be estimated in real time). Control strategies that integrate the operation of freeway ramp metering systems, driver information systems, and arterial traffic signal control systems, and that meter flow into bottleneck areas, can be developed to improve traffic control. Eventually, perhaps toward the third decade of the 21st century, totally automated facilities may be built on which vehicles would be controlled by electronics in the highway [2].

Safety

Whereas many safety measures developed over the years have been aimed at reducing the consequences of accidents (such as vehicle crashworthiness and forgiving roadside features,) many ITS functions are directed toward the *prevention* of accidents. A premise of the European PROMETHEUS program, for example, was that 50% of all rear-end collisions and accidents at crossroads and 30% of head-on collisions could be prevented if the driver was given another half-second of advance warning and reacted correctly. Over 90% of these accidents could be avoided if drivers took the appropriate countermeasures 1 second earlier. ITS technologies that involve sensing and vehicle-to-vehicle communications are initially designed to automatically warn the driver, providing enough lead time for him or her to take evasive actions. The technologies may also assume some of the control functions that are now totally the responsibility of drivers, compensating for some of their limitations and enabling them to operate their vehicles closer together but safer. Even before these crash-avoidance technologies become available to the public, ITS holds promise for improving safety by providing smoother traffic flow. For example, driver information systems provide warnings on incident blockages ahead, and this may soften the shock wave that propagates as a result of sudden and abrupt decelerations caused by unanticipated slowdowns [2].

Potential safety dangers must, however, also be acknowledged. A key issue involves driver distraction and information overload from the various warning and display devices in the vehicle. Other issues include dangers resulting from system unreliability (for example, a warning or driver-aid system that fails to operate) and the incentive for risky driving that ITS technologies may provide. These are important research issues that must be addressed before such systems are widely implemented [2].

Productivity

The availability of accurate, real-time information will be especially useful to operators of vehicle fleets, including transit, high-occupancy vehicle (HOV), emergency, fire, and police services, as well as truck fleets. Operators are able to know where their vehicles are and may receive an estimate on how long a trip can be expected to take; thus, they will be able to advise on best routes to take and will be able to manage their fleets better [2].

There is great potential for productivity improvements in the area of regulation of commercial vehicles. Automating and coordinating regulatory requirements through application of ITS technologies can, for example, reduce delays incurred at truck weigh stations, reduce labor costs to the regulators, and minimize the frustration and costs of red tape to long-distance commercial vehicle operators. There is also potential to improve coordination among freight transportation modes; as an example, if the maritime and trucking industries used the same electronic container identifiers, as has been the case in certain limited applications, freight-handling efficiencies would be greatly improved [2].

65.3 ITS Categories

At its early stages, by general agreement, IVHS (the precursor of ITS) had been subdivided into six interlocking system areas, three focused on technology and three on applications [1]:

Technology oriented:

- Advanced Traffic Management Systems (ATMS)
- Advanced Traveler Information Systems (ATIS)
- Advanced Vehicle Control Systems (AVCS)

Applications oriented:

- Advanced Public Transportation Systems (APTS)
- Commercial Vehicle Operations (CVO)
- Advanced Rural Transportation Systems (ARTS)

Advanced Traffic Management Systems

ATMS addresses technologies to monitor, control, and manage traffic on streets and highways. ATMS technologies include [1]:

- Traffic management centers (TMCs) in major metropolitan areas to gather and report traffic information, and to control traffic movement to enhance mobility and reduce congestion through ramp, signal, and lane management; vehicle route diversion; etc.
- Sensing instrumentation along the highway system, which consists of several types of sensors, including magnetic loops and machine vision systems, that provide current information on traffic flow to the TMC
- Variable message signs that provide current information on traffic conditions to highway users and suggest alternate routes
- Priority control systems to provide safe travel for emergency vehicles when needed
- Programmable, directional traffic signal control systems
- Automated dispatch of tow, service, and emergency vehicles to accident sites

Advanced traffic management systems have six primary characteristics differentiating them from the typical traffic management system of today [2]. In particular, ATMS:

- Work in real time.
- Respond to changes in traffic flow. In fact, an ATMS will be one step ahead, predicting where congestion will occur based on collected origin–destination information.
- Include areawide surveillance and detection systems.
- Integrate management of various functions, including transportation information, demand management, freeway ramp metering, and arterial signal control.
- Imply collaborative action on the part of the transportation management agencies and jurisdictions involved.
- Include rapid-response incident management strategies.

To implement ATMS, real-time traffic monitoring and data management capabilities are being developed, including advanced detection technology, such as image processing systems, automatic vehicle location and identification techniques, and the use of vehicles as probes. New traffic models are being created, including real-time dynamic traffic assignment models, real-time traffic simulation models, and corridor optimization techniques. The applicability of artificial intelligence and expert systems techniques is assessed, and applications such as rapid incident detection, congestion anticipation, and control strategy selection are being developed and tested [2].

Advanced Traveler Information Systems

ATIS address technologies to assist travelers with planning, perception, analysis, and decision making to improve the convenience and efficiency of travel. In the automobile, ATIS technologies include [1]:

- Onboard displays of maps and roadway signs (in-vehicle signing)
- Onboard navigation and route guidance systems
- Systems to interpret digital traffic information broadcasts
- Onboard traffic hazard warning systems (e.g., icy road warnings)

Outside the vehicle, ATIS technologies include [1]:

- Trip planning services
- Public transit route and schedule information available online at home, office, kiosks, and transit stops.

Advanced traveler information systems provide drivers with information about congestion and alternate routes, navigation and location, and roadway conditions through audio and visual means in the vehicle. This information can include incident location, location of fog or ice on the roadway, alternate routes, recommended speeds, and lane restrictions. ATIS provide information that assist in trip planning at home, at work, and by operators of vehicle fleets. ATIS also provide information on motorist services such as restaurants, tourist attractions, and the nearest service stations and truck and rest stops (this has been called the yellow pages function.) ATIS can include onboard displays that replicate warning or navigational roadside signs when they may be obscured during inclement weather or when the message should be changed, as when speed limits should be lowered on approaches to congested freeway segments or fog areas. An automatic Mayday feature may also be incorporated, which would provide the capability to automatically summon emergency assistance and provide vehicle location [2].

A substantial effort is required to define the communications technology, architecture, and interface standards that will enable two-way, real-time communication between vehicles and a management center. Possibilities include radio data communications, cellular systems, roadside beacons used in conjunction with infrared or microwave transmissions or low-powered radio signals, and satellite communications. Software methods to fuse the information collected at the management center and format it for effective use by various parties must also be developed. These parties include commuters, tourists, other trip makers, and commercial vehicle operators, both before they make a trip and en route; operators of transportation management systems; and police, fire, and emergency response services [2].

A number of critical human factors issues must also be investigated. These include identifying the critical pieces of information and the best way of conveying them to different individuals. The human factors issues also include a critical examination of in-vehicle display methods [2].

Advanced Vehicle Control Systems

AVCS address technologies to enhance the control of vehicles by facilitating and augmenting driver performance and, ultimately, relieving the driver of some tasks, through electronic, mechanical, and communications devices in the vehicle and on the roadway. AVCS technologies include [1]:

- Adaptive cruise control, which slows a cruise-controlled vehicle if it gets too close to a preceding vehicle
- Vision enhancement systems, which aid driver visibility in the dark or in adverse weather
- Lane departure warning systems, which help drivers avoid run-off-the-road crashes
- Automatic collision avoidance systems, i.e., automatic braking upon obstacle detection
- Automated Highway Systems (AHS), automatically controlling vehicles in special highway lanes to increase highway capacity and safety

Whereas the other categories of ITS primarily serve to make traveling more efficient by providing more timely and accurate information about transportation, AVCS serve to greatly improve safety and potentially make dramatic improvements in highway capacity by providing information about changing conditions in the immediate environment of the vehicle, sounding warnings, and assuming partial or total control of the vehicle [2].

Early implementation of AVCS technologies may include a number of systems to aid with the driving task. These include hazard warning systems that sound an alarm or actuate a light when a vehicle moves dangerously close to an object, such as when backing up or when moving into the path of another vehicle when changing lanes. Infrared imaging systems may also be implemented that enhance driver visibility at night. AVCS technologies also include adaptive cruise control and lane-keeping systems that automatically adjust vehicle speed and position within a lane through, for example, radar systems that detect the position and speed of a lead vehicle, or possibly through electronic transmitters in the pavement that detect the position of vehicles within the lane and send messages to a computer in the vehicle that has responsibility for partial control functions. As technology advances, lanes of traffic may be set aside exclusively for automated operation, known as platooning highway systems. These automated facilities have the potential to greatly increase highway capacity while at the same time providing for safer operation [2].

Much research, development work, and testing are needed before such systems can be built and implemented, and much of it is taking place today. Perhaps the most important issues, though, relate to the role of humans in the system — that is, public acceptability and how it is likely to affect system effectiveness. Other human factors issues include driver reaction to partial or full control — whether it will cause them to lose alertness or drive more erratically. Another important area is AVCS reliability and the threat of liability [2].

The vision for the AHS program is to create a fully automated system that evolves from today's roads, beginning in selected corridors and routes; provides fully automated, "hands-off" operation at better levels of performance than there are today, in terms of safety, efficiency, and comfort; and allows equipped vehicles to operate in both urban and rural areas and on highways that are instrumented and not instrumented [7].

Although full deployment of an AHS is certainly a long-term goal, pursuit of this goal is extremely important. A new level of benefits could be realized with the complete automation of certain facilities. By eliminating human error, an automated highway could provide a nearly accident-free driving environment. In addition, the precise, automated control of vehicles on an automated vehicle–highway system could result in an increase of two to three times the capacity of present-day facilities while encouraging the use of more environmentally benign propulsion methods. Initial AHS deployments might be on heavily traveled urban or interstate highway segments, and the automated lanes might be comparable to the HOV vehicle lanes on today's highways. If successful, the AHS could evolve into a major advance of the nation's heavily traveled roadways or the interstate highway system [7].

Advanced Public Transportation Systems

APTS addresses applications of ITS technologies to enhance the effectiveness, availability, attractiveness, and economics of public transportation. APTS strives to improve performance of the public transportation system at the unit level (vehicle and operator) and at the system level (overall coordination of facilities and provision of better information to users). APTS technologies include [1]:

- Fleet monitoring and dispatch management
- Onboard displays for operators and passengers
- Real-time displays at bus stops
- Intelligent fare collection (e.g., using smart cards)
- Ride-share and HOV information systems

Applications of ITS technologies could lead to substantial improvements in bus and paratransit operations in urban and rural areas. Dynamic routing and scheduling could be accomplished through onboard devices, communications with a fleet management center, and public access to a transportation information system containing information on routes, schedules, and fares. Automated fare collection systems could also be developed that would enable extremely flexible and dynamic fare structures and relieve drivers of fare collection duties [2].

Commercial Vehicle Operations

CVO addresses applications of ITS technologies to commercial roadway vehicles (trucks, commercial fleets, and intercity buses). Many CVO technologies, especially for interstate trucking, relate to the automated, no-stop-needed handling of the routine administrative tasks that have traditionally required stops and waiting in long lines: toll collection, road-use calculation, permit acquisition, vehicle weighing, etc. Such automation can save time, reduce air pollution (most, and the worst, emissions are produced during acceleration and deceleration), and increase the reliability of record keeping and fee collection. CVO technologies include [1]:

- Automatic vehicle identification (AVI)
- Weigh-in motion (WIM)
- Automatic vehicle classification (AVC)
- Electronic placarding or bill of landing
- Automatic vehicle location (AVL)
- Two-way communications between fleet operator and vehicles
- Automatic clearance sensing (ACS)

The application of ITS technologies holds great promise for improving the productivity, safety, and regulation of all commercial vehicle operations, including large trucks, local delivery vans, buses, taxis, and emergency vehicles. Faster dispatching, efficient routing, and more timely pickups and deliveries are possible, and this will have a direct effect on the quality and competitiveness of businesses and industries at both the national and international levels. ITS technologies can reduce the time spent at weigh stations, improve hazardous material tracking, reduce labor costs to administer government truck regulations, and minimize costs to commercial vehicle operators [2].

ITS technologies manifest themselves in numerous ways in commercial vehicle operations. For example, for long-distance freight operations, onboard computers not only will monitor the other systems of the vehicle but also can function to analyze driver fatigue and provide communications between the vehicle and external sources and recipients of information. Applications include automatic processing of truck regulations (for example, commercial driver license information, safety inspection data, and fuel tax and registration data), avoiding the need to prepare redundant paperwork and leading to "transparent borders"; provision of real-time traffic information through advanced traveler information systems; proof of satisfaction of truck weight laws using weigh-in motion scales, classification devices, and automated vehicle identification transponders; and two-way communication with fleet dispatchers using automatic vehicle location and tracking and in-vehicle text and map displays. Regulatory agencies would be able to take advantage of computerized record systems and target their weighing operations and safety inspections at those trucks that are most likely to be in violation [2].

Advanced Rural Transportation Systems

ARTS address applications of ITS technologies to rural needs, such as vehicle location, emergency signaling, and traveler information. The issues involved in implementing ITS in rural areas are significantly different from those in urban areas, even when services are similar. Rural conditions include low population density, fewer roads, low amount of congestion, sparse or unconventional street addresses, etc. Different technologies and communications techniques are needed in rural ITS to deal with those conditions. Safety is a major issue in ARTS; over half of all accidents occur on rural roads. ARTS technologies include [1]:

- Route guidance
- Two-way communications
- Automatic vehicle location
- Automatic emergency signaling
- Incident detection
- Roadway edge detection

Application of ARTS technologies can address the needs of rural motorists who require assistance either because they are not familiar with the area in which they travel (tourists) or because they face extreme conditions such as weather, public works, and special events. Provision of emergency services is particularly important in rural areas. A state study [28] has determined that notification of spot hazardous conditions and collision avoidance at nonsignalized intersections are highly important issues that ARTS could address in the short term; long-term issues include construction zone assistance, transit applications, inclement weather trip avoidance and assistance, tourist en route information and traffic control, and in-vehicle Mayday devices.

65.4 ITS Restructuring and Progress

With the enactment of the Intermodal Surface Transportation Efficiency Act (ISTEA) in 1991, Congress set a new course for transportation by mandating increased efficiency and safety on the existing highway and transit infrastructure through increased emphasis on intermodalism — the seamless integration of multiple modes of transportation. In response to ISTEA, the U.S. Department of Transportation (DOT) initiated a multifaceted ITS program involving research and field operational testing of promising ITS applications. With the passage of the Transportation Equity Act for the 21st Century (TEA-21) in June 1998, Congress reaffirmed the U.S. DOT's role in continuing the development of ITS technologies and launching the transition nationwide and the integrated deployment of ITS applications to foster the management of multiple transportation resources as unified systems delivering increased efficiency, safety, and customer satisfaction. We have thus witnessed the restructuring of the ITS program from the program areas established during the ISTEA era into the new organization reflecting congressional direction in TEA-21, which emphasizes deployment and integration of ITS. The advent of TEA-21 catalyzed a restructuring of ITS program activities into intelligent infrastructure categories and the Intelligent Vehicle Initiative (IVI) [41].

The program reorientation reflects the evolution of emphasis to deployment whose output is infrastructure or vehicles. Metropolitan ITS infrastructure inherits the research in Advanced Traffic Management Systems, Advanced Public Transportation Systems, and Advanced Traveler Information Systems. The Rural ITS infrastructure encompasses the activities of the Advanced Rural Transportation Systems (ARTS) program, including the application of technologies under development for metropolitan and commercial vehicle infrastructure that are adaptable to rural community needs. The commercial vehicle ITS infrastructure continues to build on the research endeavors of the Commercial Vehicle Operations program and is heavily focused on the deployment of Commercial Vehicle Information Systems and Networks (CVISN). The Intelligent Vehicle Initiative integrates the work accomplished in various facets of intelligent vehicle research and development to include the Advanced Vehicle Control and Safety Systems (AVCSS) program and the Automated Highway Systems [41].

The enabling research and technology program area continues to provide crosscutting support to each of the four functional components constituting the program's foundation. Figure 65.1 provides a crosswalk depicting the dynamics of the realignment.

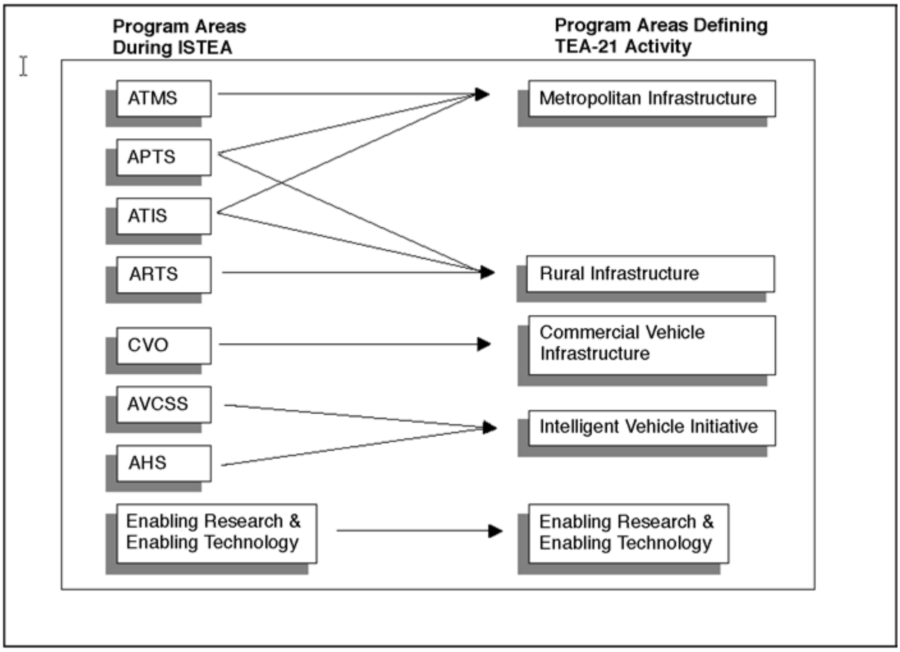


FIGURE 65.1 ITS program reorientation. (From ITS JPO, Department of Transportation's Intelligent Transportation Systems (ITS) Projects Book, U.S. DOT, FHWA Operations Core Business Unit, FTA Office of Mobility Innovation, National Highway Traffic Safety Administration, Washington, D.C., 2001.)

The restructured ITS program places emphasis in two major areas: deploying and integrating intelligent infrastructure, and testing and evaluating intelligent vehicles. Intelligent infrastructure and intelligent vehicles, working together, will provide the combinations of communications, control, and information management capabilities needed to improve mobility, safety, and traveler decision making in all modes of travel. Intelligent infrastructure comprises the family of technologies that enable the effective operation of ITS services in metropolitan areas, in rural and statewide settings, and in commercial vehicle applications. Intelligent vehicle technologies foster improvements in safety and mobility of vehicles. The Intelligent Vehicle Initiative embraces four classes of vehicles: light vehicles (ranging from passenger automobiles and vans to light trucks), transit vehicles (buses), commercial vehicles (trucks and interstate buses), and specialty vehicles (emergency response, enforcement, and maintenance vehicles).

Within this restructuring, intelligent infrastructure and intelligent vehicle program development objectives are pursued through four program areas: metropolitan ITS infrastructure, rural ITS infrastructure, commercial vehicle ITS infrastructure, and the Intelligent Vehicle Initiative, as described below, which includes light vehicles, transit vehicles, trucks, and emergency and specialty vehicles.

The metropolitan ITS infrastructure program area is focused on deployment and integration of technologies in that setting. The rural ITS infrastructure program area emphasizes deployment of high-potential technologies in rural environments. Commercial vehicle ITS infrastructure program objectives are directed at safety and administrative regulation of interstate trucking. Intelligent vehicle program objectives are centered on in-vehicle safety systems for all classes of vehicles in all geographic environments.

There are no specific ITS applications that hold the potential for addressing all of the current or projected transportation system needs. The potential for success lies in developing a national transportation system incorporating integrated and interoperable ITS services. The ITS program envisions a gradual and growing interaction between infrastructure and vehicles to produce increased benefits in mobility and traveler safety.

The documents guiding ITS program direction are evolving. The U.S. DOT's goals, key activities, and milestones for fiscal years (FY) 1999 through 2003 are documented in the National Intelligent Transportation Systems Program 5-year horizon plan [38]. This plan was followed by a 10-year program plan [46] that presents the next generation research agenda for ITS. These two documents, coupled with the Intelligent Transportation Society of America's national deployment strategy, satisfy congressional direction in TEA-21 to update the National ITS Program Plan published in 1995 and address ITS deployment and research challenges for stakeholders at all levels of government and the private sector. Within the restructured framework, the ITS program is focused on activities impacting both near-term and long-term horizons.

Near Term

Through the end of FY 2003, the effective period of TEA-21, the program will focus on facilitating integrated deployment of ITS components in the defined infrastructure categories.

Metropolitan ITS infrastructure will integrate various components of advanced traffic management, traveler information, and public transportation systems to achieve improved efficiency and safety and to provide enhanced information and travel options for the public.

Commercial vehicle ITS infrastructure is oriented on integrating technology applications for improving commercial vehicle safety, enhancing efficiency, and facilitating regulatory processes for the trucking industry and government agencies. The principal instrument of this component is known as Commercial Vehicle Information Systems and Networks, a system of information systems that link the nodes supporting communications among carriers and agencies.

Rural ITS infrastructure is characterized by a framework of seven development tracks such as surface transportation weather and winter mobility and rural transit mobility. ITS technologies are demonstrating exceptional effectiveness and customer acceptance in such applications that are tailored to rural transportation settings.

The development of a robust market fueled by private sector investment is dependent on a critical mass of basic ITS infrastructure. In the era of ISTEA, the National ITS Program focused principally on research, technology development, and field testing; the focus of TEA-21 will continue this legacy by building on successes to deploy ITS infrastructure. A critical challenge in achieving a seamless, intermodal transportation system is ensuring interoperability through the use of an open, nonproprietary architecture and the adoption of ITS standards.

Long Term

The long-term focus will be directed at supporting research, development, and testing of advanced technologies demonstrating potential for deployment in the 5- to 20-year horizon. The in-vehicle component of this effort will be consolidated into a single Intelligent Vehicle Initiative centered heavily on applying driver assistance and control intervention systems to reduce vehicle crashes. A companion effort seeks to integrate driving assistance and motorist information functions to facilitate information processing, decision making, and more effective vehicle operation.

A summary of ITS projects, tests, and studies initiated through September 2000 that have been partially or totally financed from federal ITS funds can be found in Reference 41.

65.5 What We Have Learned [32]

Now, with the National ITS Program more than a decade old in the United States, it certainly is timely, appropriate, and necessary to ask: Have we succeeded in deploying ITS? Has that deployment had a positive effect on surface transportation? What have we learned from these ITS deployments that can guide us in the future?

A recent study by the Federal Highway Administration (FHWA) [32] has addressed these questions. While many possible definitions exist, success here was tied to effectiveness — that is, whether an ITS application addresses major societal goals such as enhanced safety and improved quality of life — and to deployment of each particular ITS technology or application. Implicit in this metric for success is the belief in the test of the marketplace and the ITS community's ability to select those technologies and applications it sees as cost-effective and beneficial.

How It Was Done

The ITS Joint Program Office (JPO) of the FHWA of the U.S. DOT funds the development of several databases that are used to judge various ITS technologies and applications. These databases include the following:

- Metropolitan ITS Deployment Tracking Database, maintained by the Oak Ridge National Laboratory
- Commercial Vehicle Information Systems Network Deployment Tracking Database, maintained by the John A. Volpe National Transportation Systems Center (Volpe Center)
- 1998 Survey of Transit Agencies, conducted by the Volpe Center
- ITS cost database, maintained by Mitretek Systems

Deployment levels for various technologies were defined as follows:

- Deployed in fewer than 10% of the possible sites = limited deployment
- Deployed in 10 to 30% of the possible sites = moderate deployment
- Deployed in more than 30% of the possible sites = widespread deployment

Deployment levels are based on the actual presence of particular technologies, not future plans to deploy, even if funding for the deployment has already been secured. However, simply identifying an ITS technology or application as unsuccessful (i.e., not adequately deployed) is not a sufficient base for understanding how to subsequently advance in that area. The study, therefore, included the reason for the lack of success, choosing among three fundamental causes for a technology or application not being deployed:

1. The technology simply did not function effectively in a real-world environment.
2. While the technology or application worked in a technical sense, it was too costly, meaning any one of the following:
   A. It was simply too expensive to deploy compared with the potential benefits that accrued from its deployment.
   B. The absolute costs of acquisition, operations, and maintenance were considered too large by the deploying organization.
   C. The technology used was not suitable for a particular application.
3. Institutional barriers prevented the effective deployment of the technology or application.

Any of these reasons for lack of success could potentially be overcome in the future. Technologies can be enhanced; prices of various technologies can and do fall, often dramatically; and institutional barriers, while often tenacious, can be overcome with careful work over the long term. Further, a particular technology or application may not have had time to develop a "following" in the marketplace, given development and deployment cycles. Therefore, each technology was characterized as one of the following: successful, unsuccessful, holds promise, or jury is still out. To be sure, the deployment level does not necessarily relate directly to success. For example, a technology that is only moderately deployed could be considered successful because it serves as an appropriate technological solution, though only for a small segment of the market.

The areas included within the scope of this study are [32]: freeway, incident, and emergency management, and electronic toll collection (ETC); arterial management; traveler information systems; Advanced Public Transportation Systems; Commercial Vehicle Operations (CVO); crosscutting technical issues; and crosscutting institutional issues.

Freeway, Incident, and Emergency Management, and Electronic Toll Collection

This area includes a number of different, albeit related, technologies. Various technologies, including transportation management centers, ramp metering, dynamic message signs, roadside infrastructure, and dynamic lane and speed control, form the basis of these applications. ETC is one of the fundamental and earliest-deployed ITS technologies. It is also the most common example of the electronic linkage between vehicle and infrastructure that characterizes ITS. Freeways (i.e., limited-access highways) represent a major and early ITS application area. Incident management on those facilities is of primary importance in reducing nonrecurrent congestion. Emergency management predates ITS as a concept but is enhanced by the addition of ITS technologies.

Although a number of systems have seen widespread deployment, much more can be accomplished. Institutional issues preventing truly integrated services are a major barrier. An important technical advancement would be to upgrade such systems to be predictive (in the sense of predicting when congestion will occur in the future as a function of current traffic patterns and expectations about the future) as opposed to the responsive systems currently in place. There is a need to institutionalize operation budgets for these kinds of systems as well as a need to attract high-quality technical staff for deployment and operations support.

Arterial Management

Arterials are high-capacity roadways controlled by traffic signals, with access via cross-streets and often abutting driveways. Arterial management predates ITS, with early deployments going back to the 1960s; it is a useful ITS application with current deployment. However, adaptive control strategies, which make real-time adjustments to traffic signals based on sensing conditions (e.g., queues), at arterials are not in widespread use. While some argue that such control strategies have potential for substantial benefits, only a handful are deployed nationally, of which four are federally funded field operational tests. The reasons for this deployment lag include cost issues and concerns that algorithms for adaptive traffic control simply do not perform well. In particular, when traffic volumes are heavy, the state-of-the-art algorithms appear to break down (although vendors claim otherwise). Also, system complexity drives the need for additional training.

Widespread deployment has not yet occurred for traveler information systems for arterials, even though studies suggest safety and delay reduction benefits. The hope is that with the addition of cellular phones, or cellular phone geolocation for traffic probes, and implementation of a national three-digit traveler information number (511), more deployment will occur. Integration of various traffic management technologies with arterial management is an important next step. Integration of arterial management with emergency vehicle management, transit management, and freeway management would represent important and useful advances.

Traveler Information Systems

Traveler information is one of the core concepts of ITS. Among the items valued by consumers are high-quality information, easy and timely accessibility to that information, a high-quality user interface, and low prices, preferably free. Consumer demand for traveler information is a function of the amount of congestion on the regional transportation network, the overall characteristics of that network, what is provided on the supply side in terms of information quality and user interface, characteristics of individual trips, and driver and transit user characteristics.

Examples abound of various kinds of traveler information systems, with extensive deployment of various kinds of systems. While people value high-quality traveler information in the conceptual sense, they are not necessarily willing to pay for it. After all, free information — although often of lower quality — is universal (e.g., radio helicopter reports). So, whether traveler information systems can be a viable stand-alone commercial enterprise is likewise unclear. More likely, transportation information will be offered as part of some other package of information services. The Internet is likely to be a major basis of traveler information delivery in the future.

The analysis of traveler information systems brings home the fact that ITS operates within the environment of people's expectations for information. In particular, timeliness and quality of information are on a continually increasing slope in many non-ITS applications, with people's expectations heightened by the Internet and related concepts. Traveler information providers, whether in the public or private sector, need to be conscious of operating in the context of these changed expectations. Further, the effective integration of traveler information with network management, or transportation management systems, of which freeway and arterial management are examples, is currently virtually nonexistent. Both network management and traveler information systems would benefit by more substantial integration, as would the ultimate customers — travelers and freight carriers — of these systems.

Advanced Public Transportation Systems

That transit has difficulty attracting market share is a well-established fact. Reasons include the following: land-use patterns incompatible with transit use; lack of high-quality service, with travel times too long and unreliable; lack of comfort; security concerns; and incompatibility with the way people currently travel (for example, transit is often not suited for trip chaining). The hypothesis is that ITS transit technologies — including automatic vehicle location, passenger information systems, traffic signal priority, and electronic fare payment — can help ameliorate these difficulties, improving transit productivity, quality of service, and real-time information for transit users.

Using ITS to upgrade transit clearly has potential. However, deployment has, for the most part, been modest, stymied by a number of constraints: lack of funding to purchase ITS equipment, difficulties in integrating ITS technologies into conventional transit operations, and lack of human resources needed to support and deploy such technologies. Optimistically, there will be a steady but slow increase in the use of ITS technologies for transit management as people with ITS expertise join transit agencies. However, training is needed, and inertia must be overcome in deploying these technologies in a chronically capital-poor industry. Integrating transit services with other ITS services is potentially a major intermodal benefit of ITS transit deployments; it is hoped that this integration, including highway and transit, multiprovider services and intermodal transfers, will be feasible in the near term. Still, the question remains: How can we use ITS to fundamentally change transit operations and services? The transit industry needs a boost, and it can be vital in providing transportation services, especially in urban areas, and in supporting environmentally related programs. Can ITS be the mechanism by which the industry reinvents itself? The jury is certainly still out on that question.

Commercial Vehicle Operations

This review is limited to the public sector side of CVO systems (i.e., it does not include fleet management) as states fulfill their obligation to ensure safety and enforce other regulations related to truck operations on their highways. These systems fall under the CVISN rubric and deal with roadway operations, including safety information exchange and electronic screening, as well as back-office applications such as electronic credentialing.

While CVISN is experiencing some deployment successes, much remains to be done. Participation by carriers is voluntary in most programs, and requiring use of transponders by truckers may be difficult. Certainly these facts make universal deployment challenging. Also important as a barrier to deployment is consistency among states, particularly contiguous ones. Recognizing trucking as a regional or even national business, the interface between the trucking industry and the various states needs to be consistent for widespread deployment to occur. While each state has its own requirements for such systems, driven by its operating environment, states must work toward providing interstate interoperability. Expanded public–public partnerships are needed among states and between the federal government and states.

Some public and private sector tensions occur in the CVISN program, as well. A good example is how truckers like the technologies that support weigh station bypass, whereby they are not required to stop at a weigh station if they have been previously checked. In such systems, the information is passed down the line from an adjoining station or even another state. At the same time, truckers are concerned about equity in tax collection and the privacy of their origin–destination data, because of competitive issues. Ironically, the same underlying CVISN system drives both applications. Public–private partnerships need to be developed in this application for public and private benefits to be effectively captured.

Crosscutting Technical and Programmatic Issues

Advanced technology is at the heart of ITS, so it is helpful to consider technical issues that affect ITS functions and applications. Technical issues include how one deals with rapidly changing technologies and how this aspect relates to the need for standards. Rapid obsolescence is a problem. All in all, technology issues are not a substantial barrier to ITS deployment. Most technologies perform; the question is, are they priced within the budget of deploying organizations, and are those prices consistent with the benefits that can be achieved? Two core technologies are those used for surveillance and communication.

Surveillance technologies have experienced some successes in cellular phone use for incident reports and in video use for incident verification, but the jury is still out on cellular phone geolocation for traffic probes. The lack of traffic flow sensors in many areas and on some roadway types continues to inhibit the growth of traveler information and improved transportation management systems.

Communications technologies have experienced some success with the Internet for pretrip traveler information and credentials administration in CVO. Emerging technologies include wireless Internet and automated information exchange. The growth rate of these technologies is high. In particular, the number of Americans having access to the Internet is growing rapidly, portending increased use of ITS applications [48].

Crosscutting Institutional Issues

Institutional issues are the key barrier to ITS deployment. The ten most prominent issues are awareness and perception of ITS, long-range operations and management, regional deployment, human resources, partnering, ownership and use of resources, procurement, intellectual property, privacy, and liability. Awareness and public and political appreciation of ITS as a system that can help deal with real and meaningful issues (e.g., safety and quality of life) are central to deployment success. Building a regional perspective to deployment using public–public and public–private partnerships is important. Recognizing that one must plan for sustained funding for operations in the long term is critical. Dealing with procurement questions is an important institutional concern, and public sector agencies are not accustomed to procuring high-technology components where intellectual property is at issue.

Fundamentally, ITS deployment requires a cultural change in transportation deployment organizations that have traditionally focused on providing conventional infrastructure. No silver bullet exists for achieving this cultural change; rather, it is a continuing, ongoing, arduous process and one that must be undertaken if ITS is to be successfully deployed.

Conclusions

A useful typology for assessing the above seven areas is along the three major dimensions commonly used to characterize transportation issues: technology, systems, and institutions [35]. Technology includes infrastructure, vehicles, and hardware and software that provide transportation functionality. Systems are one step removed from the immediacy of technology and deal with how holistic sets of components perform. An example is transportation networks. Institutions refer to organizations and interorganizational relationships that provide the basis for developing and deploying transportation programs.

Technology

Four technologies are central to most ITS applications:

1. Sensing: typically the position and velocity of vehicles on the infrastructure
2. Communicating: from vehicle to vehicle, between vehicle and infrastructure, and between infrastructure and centralized transportation operations and management centers
3. Computing: processing of the large amounts of data collected and communicated during transportation operations
4. Algorithms: typically computerized methods for dynamically operating transportation systems

One overarching conclusion is that the quality of technology is not a major barrier to the deployment of ITS. Off-the-shelf technology exists, in most cases, to support ITS functionality. An area where important questions about technology quality still remain is algorithms. For example, questions have been raised about the efficacy of software to perform adaptive traffic signal control. Also, the quality of collected information may be a technical issue in some applications.

Issues do remain on the technology side. In some cases, technology may simply be considered too costly for deployment, operations, and maintenance, particularly by public agencies that see ITS costs as not commensurate with the benefits to be gained by their deployment. In other cases, the technology may be too complex to be operated by current agency staff. Also, in some cases, technology falters because it is not easy to use, either by operators or transportation customers. Nonintuitive kiosks and displays for operators that are less than enlightening are two examples of the need to focus more on user interface in providing ITS technologies.

Systems

The most important need at the ITS systems level is integration of ITS components. While exceptions can certainly be found, many ITS deployments are stand-alone applications (e.g., ETC). It is often cost-effective in the short run to deploy an individual application without worrying about all the interfaces and platforms required for an integrated system. In their zeal to make ITS operational, people often have opted for stand-alone applications — not necessarily an unreasonable approach for the first generation of ITS deployment. However, for ITS to take the next steps forward, it will be important, for reasons of both efficiency and effectiveness, to think in terms of system integration. For example, the integration of services for arterials, freeways, and public transit should be on the agenda for the next generation of ITS deployments. Further integration of services, such as incident management, emergency management, traveler information, and intermodal services, must be accomplished. While this integration certainly adds complexity, it is also expected to provide economies of scale in system deployment and improvements in overall system effectiveness, resulting in better service for freight and traveling customers.

Another aspect of system integration is interoperability — ensuring that ITS components can function together. Possibly the best example of this function is interoperability of hardware and software in vehicles and on the infrastructure (e.g., ETC devices). The electronic linkage of vehicles and infrastructure must be designed using system architecture principles and open standards to achieve interoperability. It is quite reasonable for the public to ask whether their transponders will work with ETC systems across the country or even regionally. Unfortunately, the answer most often is no. Additionally, while it is important to make this technology operate properly on a broad geographic scale, it should also work for public transportation and parking applications. Systems that need to work at a national scale, such as CVO, must provide interoperability among components. No doubt, institutional barriers to interoperability exist (e.g., different perspectives among political jurisdictions), and these barriers inhibit widespread deployment.

Another important example of needed integration is between Advanced Transportation Management Systems and Advanced Traveler Information Systems. The former provides for operations of networks, the latter for traveler information, pretrip and in-vehicle, to individual transportation customers. For the most part, these two technologies, while conceptually interlinked, have developed independently. Currently, there are limited evaluative data on the technical, institutional, and societal issues related to integrating ATMS and ATIS, whereby ATMS, which collect and process a variety of network status data and estimates of future demand patterns, provide travelers (via ATIS services) with dynamic route guidance. This integration, together with ATMS-derived effective operating strategies for the network — which account for customer response to ATIS-provided advice, can lead to better network performance and better individual routes.

Institutions

The integration of public and private sector perspectives on ITS, as well as the integration of various levels of public sector organizations, is central to advancing the ITS agenda. The major barriers to ITS deployment are institutional in nature. This conclusion should come as no surprise to observers of the ITS scene; the very definition of ITS speaks of applying "well-established technologies," so technological breakthroughs are not needed for ITS deployment. But looking at transportation from an intermodal, systemic point of view requires a shift in institutional focus that is not easy to achieve. Dealing with intra- and interjurisdictional questions, budgetary frameworks, and regional-level perspectives on transportation systems; shifting institutional foci to operations rather than construction and maintenance; and training, retaining, and compensating qualified staff are all institutional barriers to widespread deployment of ITS technologies. Thinking through how to overcome various institutional barriers to ITS is the single most important activity we can undertake to enhance ITS deployment and develop successful implementations.

Operations

Recent years have brought an increasing emphasis on transportation operations, as opposed to construction and maintenance of infrastructure, as a primary focus. ITS is at the heart of this initiative, dealing as it does with technology-enhanced operations of complex transportation systems. The ITS community has argued that this focus on operations through advanced technology is the cost-effective way to go, given the extraordinary social, political, and economic costs of conventional infrastructure, particularly in urban areas. Through ITS, it is argued, one can avoid the high up-front costs of conventional infrastructure by investing more modestly in electronic infrastructure, then focusing attention on effectively operating that infrastructure and the transportation network at large.

While ITS can provide less expensive solutions, they are not free. There are up-front infrastructure costs and additional spending on operating and maintaining hardware and software. Training staff to support operations requires resources. Spending for ITS is of a different nature than spending for conventional infrastructure, with less up front and more in the out years. Therefore, planning for operations requires a long-term perspective by transportation agencies and the political sector. For that reason, it is important to institutionalize operations within transportation agencies. Stable budgets need to be provided for operations and cannot be the subject of year-to-year fluctuation and negotiation, which is how maintenance has traditionally been, if system effectiveness and efficiency are to be maintained. Human resource needs must be considered as well.

To justify ITS capital costs as well as continuing costs, it is helpful to consider life cycle costing in the evaluation of such programs. The costs and benefits that accrue over the long term are the important metric for such projects. But organizations need to recognize that a lack of follow-through will cause those out-year benefits to disappear as nonmaintained ITS infrastructure deteriorates and algorithms for traffic management are not recalibrated.

Mainstreaming

The term *mainstreaming* is used in different ways in the ITS setting. Some argue that mainstreaming means integrating ITS components into conventional projects. A good example is the Central Artery/Ted Williams Tunnel project in Boston, which includes important ITS elements as well as conventional infrastructure. Another is the Woodrow Wilson Bridge on I-95, connecting Maryland and Virginia, currently undergoing a major redesign, which includes both conventional infrastructure and ITS technologies and applications. This approach has the advantage of serving as an opportunity for ITS deployment within construction or major reconstruction activities. Typically, the ITS component is a modest fraction of total project cost. Even so, ITS technologies and applications can sometimes come under close political scrutiny well beyond their financial impact on the project. For example, on the Woodrow Wilson Bridge, the decommitting of various ITS elements is being considered [49].

Another definition of ITS mainstreaming suggests that ITS projects not be protected by special funds sealed for ITS applications but that ITS should compete for funding with all other transportation projects. The advantage of this method is that ITS would compete for a much larger pool of money; the disadvantage is that ITS, in the current environment, might not compete particularly successfully for that larger pool. Those charged with spending public funds for transportation infrastructure have traditionally spent virtually all their money on conventional projects. Convincing these decision makers that funds are better spent on ITS applications may be difficult.

This issue is clearly linked to human resource development. Professionals cannot be expected to select ITS unless they are knowledgeable about it, so education of the professional cadre is an essential precondition for success of mainstreaming — by either definition. Of course, the National ITS Program must also be prepared to demonstrate that the benefits of ITS deployments are consistent with the costs incurred. Protected ITS funds — funds that can be spent only on ITS applications — may be a good transition strategy as professional education continues and ITS benefits become clearer, but in the longer run, there are advantages to ITS being mainstreamed.

Human Resources

An important barrier to success in the deployment of new technologies and applications embodied in ITS is a lack of people to support such systems. The ITS environment requires skilled specialists representing new technologies. It also needs broad generalists with policy and management skills who can integrate advanced thinking about transportation services based on new technologies [35]. The ITS community has recognized these needs, and various organizations have established substantial programs for human resource development. FHWA's Professional Capacity Building program is a premier example but not the only one. Universities have also developed relevant programs that, along with graduate transportation programs undergoing substantial ITS-related changes around the country, can provide a steady stream of talented and newly skilled people for the industry. However, we must emphasize that institutional changes in transportation organizations are needed if these people are to be used effectively and retained, as people with high-technology skills can often demand much higher salaries than are provided by public sector transportation organizations. Cultural change, along with appropriate rewards for operations staff, for example, will be necessary in organizations where the culture strongly favors conventional infrastructure construction and maintenance.

The need for political champions for ITS has long been understood in the ITS community. Here, though, we emphasize the need at all levels of implementing organizations for people with the ability to effectively deploy ITS. The political realities may require public sector organizations to "contract in" staff to perform some of the high-technology functions inherent in ITS, as opposed to permanently hiring such individuals. Also, "contracting out" — having private sector organizations handle various ITS functions on behalf of the public sector — is another option. In the short run, these options may form useful strategies. In the long run, developing technical and policy skills directly in the public agency has important advantages for strategic ITS decision making.

The Positioning of ITS

Almost from its earliest days, ITS has unfortunately been subject to overexpectations and overselling. Advocates have often promoted the benefits of ITS technologies and applications and have minimized the difficulties in system integration during deployment. Often ITS has been seen by the public and politicians as a solution looking for a problem. Overtly pushing ITS can be counterproductive. Rather, ITS needs to be put to work in solving problems that the public and agencies feel truly exist.

Safety and quality of life are the two most critical areas that ITS can address. Characterizing ITS benefits along those dimensions when talking to the public or potential deploying agencies is a good strategy. The media can also help to get the story out about ITS [37].

Operator versus Customer Perspective

Information is at the heart of ITS. The provision of information to operators to help them optimize vehicle flows on complex systems is one component. The flow of information to customers (drivers, transit users, etc.) so they can make effective choices about mode, route choice, etc. is another component. There is a great deal of overlap in these two information sets, yet sharing information between operators and customers is often problematic. Operators are usually public sector organizations. From their perspective, the needs of individual travelers should be subordinate to the need to make the overall network perform effectively. On the other hand, private sector information providers often create and deliver more tailored information focusing on the needs of particular travelers rather than overall system optimization.

It is not surprising that the agendas of the public sector agencies operating the infrastructure and those of the information-provider private sector companies differ. Nonetheless, it seems clear that the ultimate customer — the traveler — would benefit from a more effective integration of these two perspectives. This issue is both a technical and an institutional one and is an important example of the need for service integration.

Regional Opportunities

From a technological and functional point of view, ITS provides, for the first time, an opportunity to manage transportation at the scale of the metropolitan-based region. Along with state or even multistate geographic areas, metropolitan-based regions — the basic geographic unit for economic competition and growth [34] and for environmental issues — can now be effectively managed from a transport point of view through ITS. While a few regions in Europe and the United States have made progress, ITS technologies generally have not been translated into a regionally scaled capability. The institutional barriers are, of course, immense, but the prize from a regional viability perspective is immense, as well. Thinking through the organizational changes that will allow subregional units some autonomy, but at the same time allow system management at the regional scale, is an ITS issue of the first order [33]. Indeed, this approach could lead to new paradigms for strategic planning on a regional scale, supported by the information and organizational infrastructure developed in the context of ITS.

The strategic vision for ITS is as the integrator of transportation, communications, and intermodalism on a regional scale [35,37]. Multistate regions with traffic coordination over very large geographic areas, as in the mountain states, is an important ITS application. Corridors such as I-95, monitored by the I-95 Corridor Coalition and stretching from Maine to Virginia, represent an ITS opportunity, as well.

Surface Transportation as a Market

Surface transportation needs to be thought of as a market with customers with ever-rising and individual expectations. Modern markets provide choices. People demand choices in level of service and often are willing to pay for superior service quality; surface transportation customers will increasingly demand this service differentiation, as well. While a market framework is not without controversy in publicly provided services, surface transportation operators can no longer think in terms of "one size fits all." High-occupancy toll (HOT) lanes, where people driving a single-occupancy vehicle are permitted to use an HOV lane if they pay a toll, are an early example of this market concept in highway transportation. HOT lanes are enabled by ITS technologies. Other market opportunities building on ITS will doubtless emerge, as well.

Assessment summaries of technologies are in Tables 65.1 through 65.9 in the Appendix.

65.6 Benefits of ITS

It is interesting to reflect on how technology has influenced transportation in the United States. The steam engine improved travel by boat and railroad, resulting in coast-to-coast systems. The internal combustion engine freed the vehicle from a fixed guideway or waterway and encouraged the construction of farm-to-market roads as well as enabled travel by air. ITS will move another step forward by providing traveler information and by operating traffic management and control systems. This quantum leap will have a major impact on today's lifestyle [6].

Attempting to quantify the benefits of widely deployed ITS technologies at the birth of what was then IVHS was similar to what planners of the U.S. interstate highway system tried to do in the 1950s. It was impossible to anticipate all of the ways that applications of ITS technology may affect society, just as planners of the interstate highway system could not have anticipated all of its effects on American society. Recognizing the importance of the issue, however, Mobility 2000, an ad hoc coalition of industry, university, and federal, state, and local government participants, whose work led to the establishment of ITS America, addressed the potential benefits of applying ITS technology in the United States. Numerous benefits were predicted for urban and rural areas and for targeted groups, such as elderly and disadvantaged travelers. Positive benefits were also found in regard to the environment [2].

ITS represents a wide collection of applications, from advanced signal control systems to ramp meters to collision warning systems. In order to apply ITS technologies most effectively, it is important to know which technologies are most effectively addressing the issues of congestion and safety. Some technologies provide more cost-effective benefits than others, and as technology evolves, the choices to deployers change. Often, several technologies are combined in a single integrated system, providing synergistic benefits that exceed the benefits of any single technology. It is important to know which technologies and technology combinations provide the greatest benefits, so that transportation investments can be applied most effectively to meet the growing transportation demands of our expanding economy [40].

Since 1994, the U.S. DOT's ITS Joint Program Office has been actively collecting information on the impacts that ITS and related projects have on the operation and management of the nation's surface transportation system. The evaluation of ITS is an ongoing process. Significant knowledge is available for many ITS services, but gaps in knowledge also exist [39]. In general, all ITS services have shown some positive benefit, and negative impacts are usually outweighed by other positive results. For example, higher speeds and improved traffic flow result in increases in nitrous oxides, while other measures that indicate increased emissions, such as fuel consumption, travel time, and delay, are reduced. Because of the nature of the data, it is often difficult to compare data from one ITS project to another. This is because of the differences in context or conditions between different ITS implementations. Thus, statistical analysis of the data is not done across data points. In several cases, ranges of reported impacts are presented and general trends can be discussed. These cases include traffic signal systems, automated enforcement, ramp metering, and incident management [39].

Most of the data collected to date are concentrated within metropolitan areas. The heaviest concentrations of such data are in arterial management systems, freeway management, incident management, transit management, and regional multimodal traveler information. Most of the available data on traffic signal control systems are from adaptive traffic control. For freeway management, most data are concentrated around benefits related to ramp metering. There are also recent studies on the benefits of ITS at highway–rail intersections.

There has been an increase in the implementation and evaluation of rural ITS. Several state and national parks are now examining and implementing improved tourism and travel information systems, and several rural areas are implementing public travel services. Many states are examining the benefits of incorporating ITS, specifically weather information, into the operation and maintenance of facilities and equipment. Many of the data reported for rural ITS are concentrated in the areas of crash prevention and security. A significant amount of information is available for road weather management activities, including winter weather–related maintenance, pavement condition monitoring, and dissemination of road weather information.

ITS for Commercial Vehicle Operations (ITS/CVO) continues to provide benefits to both carriers and state agencies. ITS/CVO program areas usually report benefits data from directly measurable effects. Therefore, it might be expected that these data are accurate and only a few data points would be necessary to convince carriers, states, and local authorities of the possible benefits of implementing these systems. To date, most of the data collected for ITS/CVO are for cost, travel time, and delay savings for carrier operations.

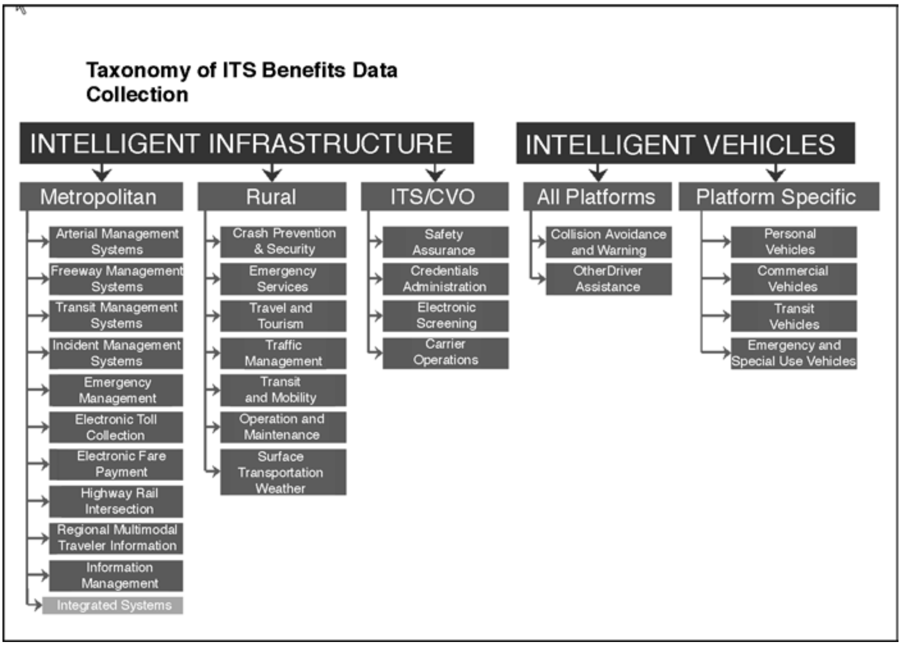


FIGURE 65.2 ITS benefits taxonomy. (Mitretek Systems, *Taxonomy for Classification of ITS Benefits*, Department of Transportation ITS JPO, Washington, D.C., June 2000.)

ITS program areas and user services associated with driver assistance and specific vehicle classes are still being developed and planned. As market penetrations increase and improved systems are developed, there will be ample opportunity to measure and report data based on actual measurements [39].

Taxonomy and Measures of Effectiveness

To track the progress toward meeting ITS program goals, the JPO has identified and established a set of measures of effectiveness. These measures are termed "A Few Good Measures" and are used as a standard in the reporting of much of the ITS benefits data currently available. Data collected are not limited to these measures; additional measures are also reported when available. The few good measures are:

- Safety: usually measured by impacts on crashes, injuries, fatalities
- Delay: usually measured in units of time
- Cost: measured in monetary amount
- Effective capacity: measured in throughput or traffic volumes
- Customer satisfaction: usually results from user surveys
- Energy and environment: usually measured in fuel consumption and emissions

The benefits database desk reference (Fig. 65.3) provides a brief summary of the metropolitan data available in the online database. The desk reference is updated regularly and is also available at the database web site. It is based on a taxonomy developed [42] for the classification of benefits (Fig. 65.2).

A cost database is also available and can be found through the ITS web page of the U.S. DOT [44], with more details in reference 45. The ITS unit cost database consists of cost estimates for a set of ITS elements. These cost estimates are categorized as capital, and operating and maintenance (O&M) costs (also known as nonrecurring and recurring costs, respectively). These costs are presented in a range to capture the lows and highs of the cost elements from the different data sources identified on the cost data sources page. The cost data are useful in developing project cost estimates during the planning process. However, the user is encouraged to find local and regional data sources and current vendor data

Metropolitan Benefits By Program Area

Program Area/Benefit Measure		Summary
Arterial Management Systems	Safety Improvements	Automated enforcement of traffic signals has reduced red-light violations 20–75%.
	Delay Savings	Adaptive signal control has reduced traffic delay 14–44%. Transit signal priority has reduced bus journey times by 7%.
	Throughput	
	Customer Satisfaction	In Michigan, 72% of surveyed drivers felt "better off" after signal control improvements.
	Cost Savings	Transit signal priority on a Toronto Transit Line allowed same level-of-service with less rolling stock.
	Environmental	Improvements to traffic signal control have reduced fuel consumption 2–13%.
	Other	Between 1969 and 1976, traffic signal preemption systems in St. Paul, MN, reduced emergency vehicle accidents by 71%.
Freeway Management Systems	Safety Improvements	Ramp Metering has shown a 15–50% reduction in crashes.
	Delay Savings	In Minneapolis-St. Paul, MN, ramp metering has reduced freeway travel time 22%, for an annual savings of 25,121 vehicle-hours.
	Throughput	Ramp metering has increased throughput 13–16%.
	Customer Satisfaction	After the Twin Cities ramp meter shutdown test, 69% of travelers supported modified continued operations.
	Cost Savings	The GA Navigator (integrated system) supported incident delay reductions, for an annual savings of $44.6 million.
	Environmental	
	Other	Ramp metering has shown an 8–60% increase in freeway speeds.
Transit Management Systems	Safety Improvements	In Denver, AVL systems with silent alarms have supported a 33% reduction in bus passenger assaults.
	Delay Savings	CAD/AVL has improved on-time bus performance 9–23%.
	Throughput	
	Customer Satisfaction	In Denver, installation of CAD/AVL decreased customer complaints by 26%.
	Cost Savings	In San Jose, AVL has reduced paratransit expense from $4.88 to $3.72 per passenger.
	Environmental	
	Other	More efficient bus utilization has resulted in a 4–9% reduction in fleet size.
Incident Management Systems	Safety Improvements	In San Antonio, integrated VMS and incident management systems decreased accidents by 2.8%.
	Delay Savings	Incident management in city and regional areas has saved 0.95–15.6 million vehicle-hours of delay per year.
	Throughput	
	Customer Satisfaction	Customers have been very satisfied with service patrols (hundreds of letters).
	Cost Savings	Cost savings have ranged from 1–45 million dollars per year, depending on coverage area size.
	Environmental	Models of the Maryland CHART system have shown fuel savings of 5.8 million gallons per year.
	Other	The I-95 TIMS system in PA has decreased highway incidents 40% and cut closure time 55%.
Emergency Management Systems	Safety Improvements	In Palm Beach, GPS/AVL systems have reduced police response times by 20%.
	Delay Savings	
	Throughput	
	Customer Satisfaction	95% of drivers equipped with PushMe Mayday system felt more secure.
	Cost Savings	
	Environmental	
	Other	

FIGURE 65.3 Metropolitan benefits.

to perform a more detailed cost estimate. The set of ITS elements is based primarily on the unit cost elements in the National ITS Architecture Cost Analysis and the ITS Deployment Analysis System (IDAS) equipment list. IDAS is software developed by the Federal Highway Administration [44] that can be used in planning for ITS deployment. IDAS can estimate relative costs and benefits for more than 60 types of ITS investments. Practitioners will find a number of useful features that enhance ITS planning.

Metropolitan Benefits By Program Area		
Program Area/Benefit Measure		**Summary**
Electronic Toll Collection	Safety Improvements	Driver uncertainty about congestion contributed to a 48% increase in accidents at E-PASS toll stations in Florida.*
	Delay Savings	The New Jersey Turnpike Authority (NJTA) E-Zpass system has reduced vehicle delay by 85%.
	Throughput	Tappan Zee Bridge: Manual lane 400–450 vehicles/hour (vph), ETC lane 1000 vph.
	Customer Satisfaction	
	Cost Savings	ETC has reportedly reduced roadway maintenance and repair costs by 14%
	Environmental	NJTA models indicate E-Zpass saves 1.2 mil gallons of fuel per yr, 0.35 tons of VOC per day, and 0.056 tons NOx per day.
	Other	20% of travelers on two bridges in Lee County, FL, adjusted their departure times as a result of value pricing at electronic tolls.
Electronic Fare Payment	Safety Improvements	
	Delay Savings	
	Throughput	
	Customer Satisfaction	Europe has enjoyed a 71–87% user acceptance of smart cards for transit/city coordinated services.
	Cost Savings	The Metro Card System saved New York approximately $70 million per year.
	Environmental	
	Other	
Highway Rail Intersections	Safety Improvements	In San Antonio, VMS with railroad crossing delay information decreased crashes by 8.7%.
	Delay Savings	
	Throughput	
	Customer Satisfaction	School bus drivers felt in-vehicle warning devices enhanced awareness of crossings.
	Cost Savings	
	Environmental	Automated horn warning systems have reduced adjacent noise impact areas by 97%.
	Other	
Regional Multimodal Traveler Information	Safety Improvements	IDAS models show the ARTIMIS traveler information system has reduced fatalities 3.2% in Cincinnati and Northern Kentucky.
	Delay Savings	A model of SW Tokyo shows an 80% decrease in delay if 15% of vehicles shift their departure time by 20 min.
	Throughput	
	Customer Satisfaction	38% of TravTek users found in-vehicle navigation systems useful when travelling in unfamiliar areas.
	Cost Savings	
	Environmental	EPA-model estimates of SmarTraveler impacts in Boston show 1.5% less NOx and 25% less VOC emissions.
	Other	Models of Seattle show freeway-ATIS is 2x more effective in reducing delay if integrated with arterial ATIS.

Source: http://www.benefitcost.its.dot.gov *Database also includes negative impacts of ITS Date: 12/31/2001

FIGURE 65.3 Metropolitan benefits (continued).

One of the powerful aspects of ITS is the capability of components to share information and resources with other components. This integration of individual components allows the formation of a unified regional traffic control and management system. To better describe the flow of information between components, a number of integration links have been developed for the metropolitan ITS infrastructure. These links represent both inter- and intracomponent sharing of information. Each of the links has been assigned a number and an origin or destination path from one component to another. For example, metropolitan integration link number 29 is from transit management to incident management and represents the ability of transit agencies to notify incident management agencies of incident location, severity, and type. Figure 65.4 depicts the links in metropolitan integration, and definitions of the links can be found in Table 65.10 in the Appendix [43].

For a more complete understanding of these components, integration, and how they can be interpreted, refer to the following documents: "Tracking the Deployment of Integrated Metropolitan Intelligent Transportation Systems Infrastructure in the USA: FY 1997 Results," Document 5883, September 1998;

Metropolitan Benefits By Measure		
Benefit Measure/Program Area		**Summary**
Safety Improvements	Arterial Management	Automated enforcement of traffic signal has reduced red-light violations 20–75%.
	Freeway Management	Ramp metering has shown a 15–50% reduction in crashes.
	Transit Management	In Denver, AVL systems with silent alarms have supported a 33% reduction in bus passenger assaults.
	Incident Management	In San Antonio, integrated VMS and incident management systems decreased accidents by 2.8%.
	Emergency Management	In Palm Beach, GPS/AVL systems have reduced police response times by 20%.
	Electronic Toll Collection	Driver uncertainty about congestion contributed to a 48% increase in accidents at E-PASS toll stations in Florida.*
	Electronic Fare Payment	
	Highway Rail Intersection	In San Antonio, VMS with railroad crossing delay information decreased crashes by 8.7%.
	Regional Traveler Info.	IDAS models show the ARTIMIS traveler information system has reduced fatalities 3.2% in Cincinnati and Northern KY.
Delay Savings	Arterial Management	Adaptive signal control has reduced traffic delay 14–44%. Transit signal priority has reduced bus journey times by 7%.
	Freeway Management	In Minneapolis-St. Paul, MN ramp metering has reduced freeway travel time 22%, for an annual savings of 25,121 vehicle-hours.
	Transit Management	CAD/AVL has improved on-time bus performance 9–23%.
	Incident Management	
	Emergency Management	
	Electronic Toll Collection	The New Jersey Turnpike Authority (NJTA) E-Zpass system has reduced vehicle delay by 85%.
	Electronic Fare Payment	
	Highway Rail Intersection	
	Regional Traveler Info.	A model of SW Tokyo shows an 80% decrease in delay if 15% of vehicles shift their departure time by 20 min.
Throughput	Arterial Management	
	Freeway Management	Ramp metering has increased throughput 13–16%.
	Transit Management	
	Incident Management	
	Emergency Management	
	Electronic Toll Collection	Tappan Zee Bridge: Manual lane 400–450 vehicles/hour (vph), ETC lane 1000 vph.
	Electronic Fare Payment	
	Highway Rail Intersection	
	Regional Traveler Info.	
Customer Satisfaction	Arterial Management	In Michigan, 72% of surveyed drivers felt “better off” after signal control improvements.
	Freeway Management	After the Twin Cities ramp meter shutdown test, 69% of travelers supported modified continued operations.
	Transit Management	In Denver, installation of CAD/AVL decreased customer complaints by 26%.
	Incident Management	Customers have been very satisfied with service patrols (hundreds of letters).
	Emergency Management	95% of drivers equipped with PushMe Mayday system felt more secure.
	Electronic Toll Collection	
	Electronic Fare Payment	Europe has enjoyed a 71–87% user acceptance of smart cards for transit/city coordinated services.
	Highway Rail Intersection	School bus drivers felt in-vehicle warning devices enhanced awareness of crossings.
	Regional Traveler Info.	38% of TravTek users found in-vehicle navigation systems useful when travelling in unfamiliar areas.

FIGURE 65.3 Metropolitan benefits (continued).

and “Measuring ITS Deployment and Integration,” Document 4372, January 1999. Both documents are available on the FHWA electronic document library [44].

Figure 65.4 illustrates the numbered links that represent the flow of information between metropolitan ITS components. Much of the data collected regarding integration illustrates benefits to delay and travel time savings or cost savings. A few evaluation studies are currently planned or in progress that may

Metropolitan Benefits By Measure		
Benefit Measure/Program Area		**Summary**
Customer Satisfaction	Arterial Management	In Michigan, 72% of surveyed drivers felt "better off" after signal control improvements.
	Freeway Management	After the Twin Cities ramp meter shutdown test, 69% of travelers supported modified continued operations.
	Transit Management	In Denver, installation of CAD/AVL decreased customer complaints by 26%.
	Incident Management	Customers have been very satisfied with service patrols (hundreds of letters).
	Emergency Management	95% of drivers equipped with PushMe Mayday system felt more secure.
	Electronic Toll Collection	
	Electronic Fare Payment	Europe has enjoyed a 71–87% user acceptance of smart cards for transit/city coordinated services.
	Highway Rail Intersection	School bus drivers felt in-vehicle warning devices enhanced awareness of crossings.
	Regional Traveler Info.	38% of TravTrek users found in-vehicle navigation systems useful when travelling in unfamiliar areas.
Cost Savings	Arterial Management	Transit signal priority on a Toronto Transit Line allowed same level-of-service with less rolling stock.
	Freeway Management	The GA Navigator (integrated system) supported incident delay reductions, for an annual savings of $44.6 million.
	Transit Management	In San Jose, AVL has reduced paratransit expense from $4.88 to $3.72 per passenger.
	Incident Management	Cost savings have ranged from 1–45 million dollars per year, depending on coverage area size.
	Emergency Management	
	Electronic Toll Collection	ETC has reportedly reduced roadway maintenance and repair costs by 14%.
	Electronic Fare Payment	The Metro Card System saved New York approximately $70 million per year.
	Highway Rail Intersection	
	Regional Traveler Info.	
Environmental	Arterial Management	Improvements to traffic signal control have reduced fuel consumption 2–13%.
	Freeway Management	
	Transit Management	
	Incident Management	Models of the Maryland CHART system have shown fuel savings of 5.8 million gallons per year.
	Emergency Management	
	Electronic Toll Collection	NJTA models indicate E-Zpass saves 1.2 mil gallons of fuel per yr, 0.35 tons of VOC per day, and 0.056 tons NOx per day.
	Electronic Fare Payment	
	Highway Rail Intersection	Automated horn warning systems have reduced adjacent noise impact areas by 97%.
	Regional Traveler Info.	EPA-model estimates of SmarTraveler impacts in Boston show 1.5% less NOx and 25% less VOC emissions.
Other	Arterial Management	Between 1969 and 1976, traffic signal preemption systems in St. Paul, MN, reduced emergency vehicle accidents by 71%.
	Freeway Management	Ramp metering has shown an 8–60% increase in freeway speeds.
	Transit Management	More efficient bus utilization has resulted in a 4–9% reduction in fleet size.
	Incident Management	The I-95 TIMS system in PA has decreased highway incidents 40% and cut closure time 55%.
	Emergency Management	
	Electronic Toll Collection	20% of travelers on two bridges in Lee County, FL, adjusted their departure times as a result of value pricing at electronic tolls.
	Electronic Fare Payment	
	Highway Rail Intersection	
	Regional Traveler Info.	Models of Seattle show freeway-ATIS is 2x more effective in reducing delay if integrated with arterial ATIS.

Source: http://www.benefitcost.its.dot.gov * Database also includes negative impacts of ITS Date: 12/31/2001

FIGURE 65.3 Metropolitan benefits (continued).

include results for several integration links. Few data have been reported for components that use information collected using arterial management (links 1 to 4). It is expected that the primary benefit for these integration links would be delay and travel time savings. The sharing of information between

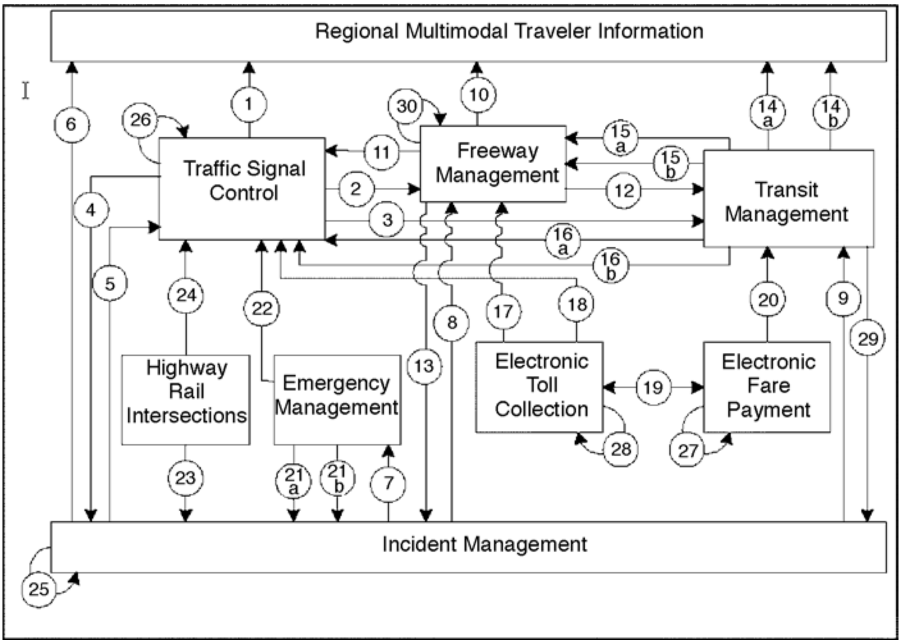


FIGURE 65.4 Metropolitan integration links. (From Mitretek Systems, ITS Benefits: Data Needs Update 2000, prepared in connection with ITS Benefits Data Needs Workshop, August 2000.)

arterial management and freeway management (links 2 and 11), which can be used to change ramp-metering rates and traffic signal times, may yield significant advantages [43].

65.7 Five-Year Plan [38]

With the passage of the Transportation Equity Act for the 21st Century in 1998, Congress reaffirmed the role of the U.S. DOT in advancing the development and integrated deployment of ITS technologies. A five-year plan was developed presenting the U.S. DOT's goals, key activities, and milestones for the National ITS Program for FY 1999 through 2003.

Transition from Research to Deployment

Under ISTEA, the National ITS Program focused primarily on research, technology development, and field testing that advanced the state of technology, demonstrated substantial public benefits, and fostered new models of institutional cooperation. The program began to lay the foundation for an information and communications infrastructure that would enable the nation to realize the vision set forth by Congress — to manage multiple transportation facilities as unified systems for greater efficiency, safety, customer service, and quality of life. TEA-21 continues the legacy of ISTEA by building on the success of research and development to date. Today, many ITS technologies are available, and the National ITS Program will shift its emphasis accordingly to the deployment of proven ITS technologies in an integrated fashion, while continuing to advance ITS capabilities through further research.

Intelligent Infrastructure and Intelligent Vehicles

The National ITS Program focuses on two main objectives: deployment of intelligent infrastructure and testing and evaluation of intelligent vehicle technologies. Intelligent infrastructure and intelligent vehicles provide the information and control needed to better manage surface transportation facilities (highways, roads, transit, and rail), to improve the safety of vehicles operating on those facilities, and to help users of all modes make better decisions about travel. Intelligent infrastructure is the necessary network of technologies — a communications and information backbone — that supports and unites key ITS services for metropolitan, rural, statewide, and commercial vehicle application. Intelligent vehicle technologies improve safety and enhance mobility of the vehicles that operate on our roadways. Such technologies apply to four classes of vehicles: light vehicles (passenger cars, vans, and light trucks), transit vehicles (buses), commercial vehicles (trucks and interstate buses), and specialty vehicles (emergency response, enforcement, and highway maintenance vehicles). ITS products and services must be seamlessly integrated and interoperable. Over time, intelligent vehicles will increasingly interact with intelligent infrastructure to yield even greater gains in mobility and traveler safety.

Intelligent infrastructure and intelligent vehicle objectives are addressed through four program areas: metropolitan ITS infrastructure, rural ITS infrastructure, commercial vehicle ITS infrastructure, and intelligent vehicles. Each program area targets a specific environment in which ITS capabilities are used. The metropolitan and rural ITS infrastructure program areas address network-based technologies deployed in those two settings. The commercial vehicle ITS infrastructure program area focuses on the integrated technologies needed specifically for safety and administrative regulation of interstate trucking. Finally, the intelligent vehicles program area targets in-vehicle safety systems for all users and geographic settings.

ITS Program Strategies

The National ITS Program utilizes eight program strategies that work cooperatively to advance the state of ITS across the country:

1. **Conducting research:** advances ITS infrastructure and vehicle capabilities by bringing technologies from visionary concepts to viable and attractive solutions to transportation problems. Continued research and development are necessary for increasing the real-time capabilities of ITS infrastructure components, improving intelligent vehicle capabilities, and developing successive generations of ITS technologies.
2. **Accelerating the development of standards:** allows communications, surveillance, monitoring, and computer processing systems to "speak" to each other, provides design guidance to manufacturers, and reassures purchasers that their systems will be compatible with other ITS elements.
3. **Building professional capacity:** ensures that transportation professionals across the country have the skills necessary to design, deploy, operate, and maintain ITS systems. ITS requires new technical skills, such as systems engineering, electronics, and communications, as well as institutional skills, which include coalition building.
4. **Creating funding incentives:** encourages more widespread integration of ITS in metropolitan, rural, and commercial vehicle settings. The overall trend in ITS funding has shifted from dedicated special funds to the use of traditional transportation funding mechanisms such as the Highway Trust Fund (including the Mass Transit Account). However, temporary funding incentives are still necessary to foster integration and national interoperability and to accelerate deployment.
5. **Providing guidance and technical assistance:** aids implementers seeking to deploy integrated ITS. The U.S. DOT provides specialized technical support through its federal field staff, through the publication of guidance documents on best practices for ITS deployment, and with the Peer-to-Peer Network, a resource composed of professionals from the private and public sectors who are on call to provide short-term, no-cost technical assistance to transportation colleagues across the country.
6. **Ensuring consistency with the National ITS Architecture and standards:** helps in planning for ITS integration, reducing development time and cost, and laying the groundwork for a seamless national ITS network. The U.S. DOT is working with stakeholders to develop federal policy on consistency and is actively training stakeholders on this issue.
7. **Evaluating the program:** essential for understanding the value and effectiveness of ITS activities and for measuring progress toward deployment goals. Tracking and evaluation are consistent with

the spirit of the Government Performance and Results Act and allow for the continual refinement of the National ITS Program.

8. **Showcasing benefits:** communicates positive results realized through the use of ITS technologies to multiple decision makers. By understanding the benefits of ITS, decision makers can compare ITS to other transportation options when addressing local transportation issues. Showcasing benefits also encourages integration of ITS systems. For example, deployment sites demonstrate successful interjurisdictional working relationships and interagency coordination. By learning about the deployment sites, decision makers better understand the operation and management planning that is necessary to achieve integration in their areas.

Program Area Goals, Key Activities, Milestones

The eight ITS program strategies are used to meet specific goals in each of the four ITS program areas: metropolitan, rural, and commercial vehicle infrastructure, and intelligent vehicles.

Metropolitan ITS Infrastructure Program Area

The metropolitan ITS program has demonstrated proven technologies for metropolitan application. Model deployments in metropolitan settings have been successful and will continue to be showcases for other areas. However, while individual systems are being purchased and installed around the country, sites are just beginning to integrate systems across jurisdictions and modes. Since integration has been limited, communities are not yet reaping the full benefits of ITS.

The metropolitan component of the National ITS Program is focused on meeting the goals for integrated deployment laid out by former Secretary of Transportation Federico Peña in 1996 and reiterated by former Secretary of Transportation Rodney Slater. Known as Operation TimeSaver, the U.S. DOT's objective is to facilitate integrated deployment of basic ITS services in 75 metropolitan areas by 2006. At present, 36 sites are considered to have some elements of integration, and additional sites show the clear beginnings of integrated systems.

Goal

By 2003, the metropolitan program aims to have 64 sites achieve the Operation TimeSaver goal for integrated deployment.

Key Activities and Milestones

The Operation TimeSaver goal will be met using all eight ITS program strategies as follows:

Conducting research: Traffic management and transit management research will be advanced under TEA-21. New models for traffic management, such as the ITS Deployment Analysis System, have been developed that more accurately represent the impact of ITS, allowing transportation planners and designers to compare ITS with other transportation options more effectively. This model was made available to the ITS planning community in 1999. A more sophisticated planning model — the Transportation Analysis and Simulation System (TRANSIMS) — is under development and will be available for initial use in 2002. In transit management, research will focus on the application of integrated transit systems through operational tests in areas such as fleet management, electronic fare payments, and traveler information. From 1999 to 2003, this research will be guided by the Federal Transit Administration's (FTA) 5-year research and technology plan.

Accelerating the development of standards: Development of standards, such as the National Transportation Communications for ITS Protocol (NTCIP) and the Transit Communications Interface Profiles (TCIP), will help facilitate integration in metropolitan areas. NTCIP will allow traffic management and operations personnel to better control, manage, and monitor virtually all the devices used on the roadway. TCIP will allow data to be shared among transit departments and other operating entities, such as emergency response services and regional traffic management centers. Because these standards are fundamental to metropolitan transportation operations, a training course on each standard is necessary. The course on NTCIP is already available, on a request basis, through the Institute of Traffic Engineers, and it will be available to stakeholders through 2003. A course on TCIP will be developed, with delivery expected to occur from 2001 to 2003.

Building professional capacity: Training courses will continue to be offered on all aspects of metropolitan ITS deployment. Courses will be updated as new information is made available.

Creating funding incentives: TEA-21 funding incentives are being offered to metropolitan public sector applicants to support technical integration and jurisdictional coordination of ITS infrastructure. Funding will be offered to both highway and transit projects, and the U.S. DOT will work with Congress and the funding recipients to ensure that both the spirit and intent of TEA-21 funding criteria are met. The U.S. DOT will allocate funding incentives annually based on programmatic goals and the criteria defined in TEA-21. Funding available for integration was set by TEA-21 at $75 million in 1999, $83 million in 2000, $83 million in 2001, $85 million in 2002, and $85 million in 2003. A maximum of 90% of this funding is available to metropolitan areas.

Providing guidance and technical assistance: Special guidance and technical assistance are being offered to transportation officials through federal field staff expertise, guidance documents, and the Peer-to-Peer Network to assist in the planning, design, operation, and maintenance of metropolitan ITS. In addition, federal field staff will work with their state and local partners to develop "ITS service plans" that outline local technical guidance needs and plans for delivery. Development of ITS service plans began with a focus on the top 78 metropolitan areas and has expanded over time to include statewide concerns that typically involve rural ITS applications. The U.S. DOT started with 62 service plans being implemented (49 from the top 78 metropolitan areas and 13 statewide plans) in FY 2000. U.S. DOT expects to expand over time and to include activities in other metropolitan areas beyond the top 78.

Ensuring consistency with the National ITS Architecture and standards: The National ITS Architecture and standards will be instrumental in catalyzing integrated ITS deployment across the country, enabling areas to meet local needs while reducing development costs and risks, facilitating future expansion capability, and fostering interoperability. Interim policy guidance on consistency with the National ITS Architecture and standards was issued in 1999. The interim guidance was implemented until release of the final policy; the final policy will be implemented through 2003 and beyond.

Evaluating the program: Program evaluations track levels of deployment and integration in the 75 metropolitan areas. Evaluations are being used to demonstrate ITS benefits and to measure progress toward the Operation TimeSaver goal. From 1999 through 2003, U.S. DOT will conduct annual tracking surveys, assemble the data received, and report findings. Using this information, the metropolitan program will be refined as appropriate.

Showcasing benefits: The four metropolitan model deployment sites funded under ISTEA — Phoenix, Arizona; Seattle, Washington; San Antonio, Texas; and the New York–New Jersey–Connecticut metropolitan area — will continue to showcase the benefits of metropolitan ITS technologies under TEA-21. These sites have brought together public and private sector partners to integrate existing infrastructure with new traveler information systems. In addition, results of deployment evaluations will be incorporated into publications to disseminate benefits information.

Through these eight strategies, the metropolitan ITS program will continue to pursue the deployment of integrated, intelligent transportation systems — including advanced traffic management, traveler information, and public transit systems — that will improve urban transportation management in the 75 largest urban areas. At the same time, there are 340 major metropolitan areas nationwide that could benefit from advanced technologies, and the U.S. DOT's field staff is working actively with all interested communities.

Rural and Statewide ITS Infrastructure Program Area

Information technologies are currently being applied in rural settings to help improve the safety and mobility of rural travelers. However, rural and statewide ITS applications are not yet as well defined as metropolitan and commercial vehicle applications. Under TEA-21, the rural program will focus primarily on research and field operational testing to further develop rural infrastructure components. Through these tests, the U.S. DOT will identify solutions that reduce the public sector costs of providing, operating, and maintaining rural ITS infrastructure. Lessons learned from the metropolitan program will be leveraged to the maximum possible extent, as will rural program resources. For example, the U.S. DOT will cooperate with other organizations and other federal departments involved in the mobility of people (such as Health and Human Services) in order to develop innovative ITS-supported services such as mobility management. Systems such as multiagency mobility management, automatic collision notification, tourist information, and weather information will be the primary focus in the early years of the program.

Goal

By 2003 the rural ITS program aims to have demonstrated in ten locations a statewide information network that is multijurisdictional and multimodal within a state and able to share data across state lines.

Key Activities and Milestones

To reach this goal, the rural ITS program will focus primarily on conducting research through operational tests. The other seven program strategies will be used to a more limited extent.

Conducting research: Seven areas have been identified for further research: surface transportation weather and winter mobility, emergency services, statewide and regional traveler information infrastructure, rural crash prevention, rural transit mobility, rural traffic management, and highway operations and maintenance. While activities are expected in all seven areas, the U.S. DOT has worked with stakeholders to categorize and prioritize the list. Initial efforts will focus on multiagency mobility management services, weather information, emergency services, and regional traveler information. Operational tests are currently under way for all four services, and additional rounds of tests will be conducted through 2003.

Accelerating the development of standards: The U.S. DOT is just beginning to identify what standards may be necessary for rural-specific ITS applications. Standards are identified by assessing user needs, defining rural ITS infrastructure, and modifying the National ITS Architecture. The rural ITS program is actively seeking stakeholder participation in this process, and modifications to the National ITS Architecture are being made as rural ITS applications are defined. Once the National ITS Architecture is revised, ITS standards requirements can be identified. U.S. DOT defined unique rural user services in 1999 and proceeded to develop them.

Building professional capacity: Professional capacity building for rural practitioners involves modifying existing ITS courses to reflect the needs of rural ITS users and exploring distance-learning opportunities. Practitioners with rural expertise will help tailor existing courses to a rural audience. Initiatives are under way to overcome barriers of limited time and travel funding experienced most acutely by rural partners. U.S. DOT is exploring methods to deliver training through satellite broadcast, CD-ROM, and the Internet. As with other parts of the National ITS Program, the U.S. DOT has planned to transfer course delivery to the National Highway Institute and National Transit Institute in 2001.

Creating funding incentives: TEA-21 funding incentives are being offered to rural public sector applicants to support deployment of individual project components and the integration of existing ITS components. Funding will be offered to both highway and transit projects, and the U.S. DOT will work with Congress and the funding recipients to ensure that both the spirit and intent of TEA-21 funding criteria are met. U.S. DOT will allocate funding annually based on programmatic goals and TEA-21 criteria. A minimum of 10% of available funding will be used in rural areas.

Providing guidance and technical assistance: The U.S. DOT will provide guidance and technical assistance primarily by disseminating the results of rural field operational tests to stakeholders. Materials, such as lessons learned and simple solutions compendia, technical toolboxes, and catalogs of available systems, will be compiled and packaged for stakeholders in an Advanced Rural Transportation Systems toolbox. Assistance also will be available to rural stakeholders through federal field staff and the Peer-to-Peer Network.

Ensuring consistency with the National ITS Architecture and standards: Interim policy guidance on consistency with the National ITS Architecture and standards was issued in October 1998. The U.S. DOT expected to issue a final policy on consistency in FY 2001. This policy will be instrumental in catalyzing integrated ITS deployment across the country. In rural areas, stakeholders will be engaged in the policy development process to work through consistency issues at the statewide planning level. The interim guidance is being implemented until release of the final policy; the final policy will be implemented through 2003 and beyond.

Evaluating the program: Rural ITS infrastructure components must be defined before they can be tracked, so program evaluation activities are just beginning. Once the components are defined, quantifiable indicators will be identified as they have been for metropolitan applications.

Showcasing benefits: In these early stages of the rural ITS program, benefits of rural ITS applications are being showcased through field operational tests. These tests are not of the same scale as the metropolitan model deployments, but they still provide rural stakeholders the opportunity to see rural ITS technologies in operation and the benefits to rural America. Tests include automatic collision notification, traveler information, weather information technologies, and traveler information in a national park setting.

Commercial Vehicle ITS Infrastructure Program Area

The commercial vehicle ITS infrastructure program focuses on increasing safety for commercial drivers and vehicles while improving operating efficiencies for government agencies and motor carriers. At the center of the program is the deployment of Commercial Vehicle Information Systems and Networks, which link existing information systems to enable the electronic exchange of information. The initial implementation of CVISN, known as Level 1, addresses safety information exchange, credentials administration, and electronic screening; it is being prototyped in two states and piloted in eight states nationwide. The U.S. DOT expected CVISN Level 1 capabilities to be achieved in Maryland, Virginia, Washington, Kentucky, California, Colorado, Connecticut, Michigan, Minnesota, and Oregon by 2000 or 2001, depending on the availability of discretionary deployment incentive funding from Congress.

Goal

The U.S. DOT has set a goal of having 26 to 30 states deploy CVISN Level 1 capabilities by 2003. Achievement of this goal will depend on the extent to which funds authorized for CVISN in TEA-21 are appropriated for that use.

Key Activities and Milestones

All eight ITS program strategies are being used to meet the commercial vehicle program area goal as follows:

Conducting research: Research efforts will continue the development, testing, and implementation of technologies necessary to support commercial vehicle safety enforcement and compliance goals. Under TEA-21, FHWA and the Federal Motor Carrier Safety Administration (FMCSA) will undertake coordinated activities intended to reduce or eliminate transportation-related incidents and the resulting deaths, injuries, and property damage. These activities include demonstrating cost-effective technologies for achieving improvement in motor carrier enforcement, compliance, and safety while keeping up with the latest technological advances. The U.S. DOT will define CVISN Level 2 capabilities and expects to demonstrate prototype technologies in two or three states from 2000 through 2003.

Accelerating the development of standards: The U.S. DOT will continue to update and maintain the CVISN architecture to ensure consistency and interoperability, to include lessons learned from deployments, and to keep current with changing technology. In addition, two standards — electronic data interchange (EDI) and dedicated short-range communication (DSRC) — are essential to the demonstration of CVISN. EDI supports safety information and credential information exchange and has been approved. The U.S. DOT has completed a DSRC standard at 5.9 GHz, which is necessary for vehicle-to-roadside exchange of information. The U.S. DOT's emphasis has shifted to developing guidelines for compatibility and certification testing of the DSRC standard. Ultimately, independent testing organizations will be responsible for certification testing of DSRC.

Building professional capacity: Professional capacity building is critical to states, vendors, and FHWA and FMCSA project managers in order to implement CVISN. In addition to the current suite of commercial vehicle ITS awareness and deployment courses, training and technical assistance will be available to states in the areas of interoperability testing for conformance with the National ITS Architecture, systems integration issues and lessons learned, and commercial vehicle ITS project monitoring and maintenance.

Creating funding incentives: TEA-21 authorized $184 million over 6 years to deploy CVISN in a majority of states. Funding was allocated based on programmatic goals and TEA-21 criteria as follows: $27.2 million in 1999, $30.2 million in 2000, $32.2 million in 2001, $33.5 million in 2002, and $35.5 million in 2003. The funding will assist prototype and pilot states, as well as other interested states, in reaching CVISN Level 1 capabilities.

Providing guidance and technical assistance: The U.S. DOT has developed an integrated strategy to support states through the deployment of CVISN. From 1999 through 2003, U.S. DOT will continue to provide support to states through tool kits, guides, the Peer-to-Peer Network, and outreach.

Ensuring consistency with the National ITS Architecture and standards: The interim guidance issued in October 1998 and the final policy expected in 2001 apply equally to commercial vehicle ITS applications. At the heart of CVISN is the need for interoperability among federal, state, carrier, and other commercial vehicle systems and networks that allow the exchange of data. The development of a policy to ensure consistency with the National ITS Architecture and approved standards supports this interoperability. Federal field staff will implement the policy through 2003 and beyond.

Evaluating the program: Deployment tracking surveys will be conducted for all 50 states at 2-year intervals from 1999 to 2003. In addition, field operational tests will be completed and results will be incorporated into ITS costs and benefits databases.

Showcasing benefits: All eight pilot states serve as model deployments to showcase the benefits of CVISN. Benefits information were collected from the sites and incorporated into brochures and materials for distribution to stakeholders in 1999 and 2000. CVISN technologies were also showcased across the country in 1999 and 2000 with the commercial vehicle technology truck, a traveling classroom that contains commercial vehicle technologies and provides an interactive learning environment for stakeholders.

Intelligent Vehicle Initiative Program Area

Under ISTEA, U.S. DOT research in crash avoidance, in-vehicle information systems, and Automated Highway Systems pointed to new safety approaches and promising solutions that could significantly reduce motor vehicle crashes. Preliminary estimates by the National Highway Traffic Safety Administration showed that rear-end, lane change, and roadway departure crash avoidance systems have the potential, collectively, to reduce motor vehicle crashes by one sixth, or about 1.2 million crashes annually. Such systems may take the form of warning drivers, recommending control actions, and introducing temporary or partial automated control of the vehicle in hazardous situations. These integrated technologies can be linked to in-vehicle driver displays that adhere to well-founded human factors requirements. The U.S. DOT has harnessed these efforts into one program, the Intelligent Vehicle Initiative (IVI).

Goal

IVI is focused on working with industry to advance the commercial availability of intelligent vehicle technologies and to ensure the safety of these systems within the vehicles.

Key Activities and Milestones

This program is solely a research effort; therefore, only the conducting research program strategy applies.

Conducting research: Intelligent vehicle research aims to identify in-vehicle technologies to counter a series of problems that are major causes of vehicle crashes. To help speed the development of solutions, IVI has been organized into manageable tasks by dividing the spectrum of problems into eight problem areas and segmenting vehicle types into four vehicle platforms. Each problem area will be studied in the platform(s) where new technologies are most needed and can be readily adopted. Currently, the IVI program is moving forward through pilot research and testing projects within each platform. Projects range from defining safety needs for specialty vehicles to widespread initial trial deployment of automatic collision notification systems for light vehicles. In general, the light and commercial vehicle platforms are further along in the process because they benefited from prior research. However, the transit and specialty vehicle platforms will advance rapidly by adapting research conducted in the other platforms. In addition to the core in-vehicle technologies, the IVI program will also begin to explore possible vehicle infrastructure cooperative technologies as well as ways to help improve the ability of drivers to receive and process more information in the vehicle.

Eight IVI problem areas:
- Rear-end collision avoidance
- Lane change and merge collision avoidance
- Road departure collision avoidance
- Intersection collision avoidance
- Vision enhancement
- Vehicle stability
- Safety-impacting services
- Driver condition warning

Four IVI platforms:
- Light vehicles
- Commercial vehicles
- Transit vehicles
- Specialty vehicles

To accomplish programmatic objectives, IVI is undertaking public and private partnerships with the motor vehicle industry and infrastructure providers. For transit, key partnerships with fleet operators will also be necessary, as transit vehicle designs are influenced not only by the vehicle manufacturers but also by transit agencies. The U.S. DOT will use multiple platforms to allow the program to focus initial research on the classes of vehicles where new technology will be adopted most quickly. Other vehicle types can then be equipped with the proven technology. The U.S. DOT will also study linkages with intelligent infrastructure, multiple systems integration, generations of vehicles with increased capabilities, and human factors. Finally, peer review will be used to help keep the goals and objectives of the program on target. Under TEA-21, the intelligent vehicle program was to form a public or private partnership to mutually govern and conduct enabling research for intelligent vehicles, engage the Transportation Research Board for a multiyear peer review, and complete initial operational tests on all platforms by 2001.

Additional Areas Covered in the Plan

In addition to program area goals and activities, this report also covers the National ITS Architecture and ITS standards, emerging program activities, and an update of ITS user services.

The National ITS Architecture and ITS Standards

The full benefits of ITS cannot be realized unless systems are integrated, rather than deployed as individual components. At the urging of public and private sector stakeholders, the U.S. DOT is facilitating system integration and technical interoperability through the development of the National ITS Architecture and ITS standards. The National ITS Architecture is a framework that defines the functions performed by ITS components and the ways in which components can be integrated into a single system. It can be used to help agencies plan and design both projects and deployment approaches that meet near-term needs while keeping options open for eventual system expansion and integration. The U.S. DOT will ensure that the National ITS Architecture responds to changing needs of the National ITS Program and the ITS industry by keeping the architecture up-to-date and relevant as new ITS applications emerge.

Since the inception of the ITS Program under ISTEA, stakeholders have recognized that ITS standards are necessary to achieve technical interoperability. Without technical standards, state and local governments, as well as consumers, risk buying products that do not necessarily work together or consistently in different parts of the country. The U.S. DOT is facilitating the creation of technical standards to minimize public sector risk in procuring these products. The overall goal of the ITS standards program is to have a comprehensive set of ITS standards developed and routinely used as states and localities deploy integrated, intermodal systems.

Over the past several years, the U.S. DOT has funded standards development organizations in conjunction with industry volunteer support to accelerate the traditional standards development process. Under TEA-21, the U.S. DOT expects that all ITS standards identified in the baseline National ITS Architecture will be developed and that the ITS standards program will increasingly focus on implementation. A first step in this direction will include the testing of approved ITS standards under realistic transportation conditions. Additionally, the U.S. DOT worked with the ITS user community in FY 1999 to identify critical ITS standards. In a report to Congress, 17 standards were identified as critical for national interoperability or as foundation standards for the development of other critical standards. Development of critical standards will be actively monitored, and provisional standards may be established.

Emerging Program Activities

As the National ITS Program evolves and transportation opportunities arise, it becomes apparent that new areas can benefit from ITS. Five such areas will be addressed under TEA-21: intermodal freight, ITS data archiving, rail transit, pedestrian and bicycle safety, and accessibility.

The goal of the emerging **intermodal freight** program is to facilitate goods movement around congested areas, across multiple modes, and with international trading partners to the north and south. The application of advanced information and communications technologies to the intermodal system offers opportunities to strengthen the links between the separate modal systems that currently operate as competitors. Under TEA-21, the intermodal freight program will conduct field operational tests to identify benefits and opportunities for ITS applications for border and corridor safety clearance applications and for intermodal freight applications that enhance operational efficiency. By 2001, the U.S. DOT expected to have enough information to develop an intermodal freight ITS to be added to the National ITS Architecture.

ITS data archiving addresses the collection, storage, and distribution of ITS data for transportation planning, administration, policy, operations, safety analyses, and research. The recently approved archived data user service, the 31st user service in the National ITS Architecture, addresses this new area and was integrated into the architecture in early FY 2000.

Rail transit is an important transit mode that historically has used advanced technologies in its operations. However, little attention has focused on how rail can benefit from system integration and ITS information. The U.S. DOT aims to address rail transit as a part of identifying integrated transit systems across agencies, modes, or regions.

Efforts toward **pedestrian and bicycle safety** focus on creating more pedestrian-friendly intersections through the use of adaptive crosswalk signals, inclusion of pedestrian and bicycle flows in traffic management models, and the promotion of in-vehicle technologies to detect and avert impending vehicle–pedestrian collisions.

Accessibility: Improvement can be made in this area, especially for rural Americans, with better information coordination and dispatching for ride sharing, paratransit, and other public transit efforts. Moreover, efforts will be aimed at improving mobility and safety for two user groups underserved by current pedestrian crossings: the elderly and the disabled. The U.S. DOT will support ITS solutions that meet the needs of these Americans.

Update of ITS User Services

The National ITS Program focuses on the development and deployment of a collection of interrelated user services. These are areas in which stakeholders have identified potential benefits from advanced technologies that improve surface transportation operations. The user services have guided the development of the National ITS Architecture and ITS standards, as well as research and development of ITS systems. In 1993, the ITS America National Program Plan introduced a set of ITS user services and subservices. When the 1995 National ITS Program Plan was published, 29 user services were identified. However, in keeping with the evolving nature of the National ITS Architecture, two new services have been identified: highway–rail intersection and the archived data user service.

ITS solutions for highway–rail intersections aim to avoid collisions between trains and vehicles at highway–rail grade crossings. Examples of intersection control technologies include advisories and alarms to train crews, roadside variable message signs, in-vehicle motorist advisories, warnings, automatic vehicle stopping, improved grade crossing gates and equipment, and automated collision notification.

Archived data services require ITS-related systems to have the capability to receive, collect, and archive ITS-generated operational data for historical purposes and for secondary users. ITS technologies generate massive amounts of operational data. These data offer great promise for application in areas such as transportation administration, policy, safety, planning, operations, safety analyses, and research. Intelligent transportation systems have the potential to provide data needed for planning performance monitoring, program assessment, policy evaluation, and other transportation activities useful to many modes and for intermodal applications. Below are listed all 31 ITS user services, including the two new ones. The user services have been grouped together in seven areas: travel and traffic management, public transportation management, electronic payment, Commercial Vehicle Operations, emergency management, advanced vehicle safety systems, and information management.

ITS user services are defined not along lines of common technologies but rather by how they meet the safety, mobility, comfort, and other needs of transportation users and providers. They represent essential, but not exclusive, ITS products and services.

Travel and traffic management:
- Pretrip travel information
- En route driver information
- Route guidance
- Ride matching and reservation
- Traveler services information
- Traffic control
- Incident management
- Travel demand management
- Emissions testing and mitigation
- Highway–rail intersection*

Public transportation management:
- Public transportation management
- En route transit information
- Personalized public transit
- Public travel security

Electronic payment:
- Electronic payment services

Commercial Vehicle Operations:
- Commercial vehicle electronic clearance
- Automated roadside safety inspection

*User service added since the first edition of the National ITS Program Plan in 1995.

Onboard safety monitoring
Commercial vehicle administrative processes
Hazardous material incident response
Commercial fleet management

Emergency management:
Emergency notification and personal security
Emergency vehicle management

Advanced vehicle safety systems:
Longitudinal collision avoidance
Lateral collision avoidance
Intersection collision avoidance
Vision enhancement for crash avoidance
Safety readiness
Precrash restraint deployment
Automated vehicle operation

Information management:
Archived data user service*

65.8 "The National Intelligent Transportation Systems Program Plan: A Ten-Year Vision" [46]

The Goals

"The National Intelligent Transportation Systems Program Plan: A Ten-Year Vision" sets forth the next-generation research agenda for ITS. It identifies benefits areas and associated goals against which change and progress can be measured. These goals provide the guideposts for fully realizing the opportunities that ITS technology can provide in enhancing the operation of the nation's transportation systems, in improving the quality of life for all citizens, and in increasing user satisfaction, whether for business or personal travel. The goals include:

Safety: reduce annual transportation-related fatalities by 15% overall by 2011, saving 5000 to 7000 lives per year

Security: have a transportation system that is well protected against attacks and responds effectively to natural and manmade threats and disasters, enabling the continued movement of people and goods, even in times of crisis

Efficiency and economy: save at least $20 billion per year by enhancing throughput and capacity with better information, better system management, and the containment of congestion by providing for the efficient end-to-end movement of people and goods, including quick, seamless intermodal transitions

Mobility and access: have universally available information that supports seamless, end-to-end travel choices for all users of the transportation system

Energy and environement: save a minimum of 1 billion gallons of gasoline each year and reduce emissions at least in proportion to this fuel saving

This plan develops a series of programmatic and enabling themes to describe the opportunities, benefits, and challenges of the transportation system of the future and activities required to realize this system.

Programmatic Theme 1

A new, bold transportation vision is needed to set the directions and mold the institutions for the next 50 years. This new, bold vision is based on information management and availability, on connectivity,

*User service added since the first edition of the National ITS Program Plan in 1995.

and on system management and optimization — in short, the creation of an Integrated Network of Transportation Information.

Programmatic Theme 2

Transportation-related safety is clearly more than safe driving. However, in recent years, motor vehicle crashes have resulted in more than 40,000 fatalities and more than 3 million injuries each year. Driver error remains the leading cause of crashes, cited in more than 80% of police crash reports. In-vehicle systems, infrastructure improvements, and cooperative vehicle infrastructure systems can help drivers avoid hazardous mistakes by minimizing distraction, helping in degraded driving conditions, and providing warnings or control in imminent crash situations.

Programmatic Theme 3

Getting emergency response teams as quickly as possible to the scene of a crash or other injury-producing incident is critical to saving lives and returning roadways to normal, unimpeded operation. ITS technologies, coupled with computer-aided dispatch, wireless communications, records management systems, private call centers, and websites, can be used to achieve these objectives.

Programmatic Theme 4

Advanced transportation management involves using advanced technology to intelligently and adaptively manage the flow of goods and people through the physical infrastructure.

Enabling themes set the stage and lay the groundwork for the application of technology to surface transportation.

Enabling Theme 1

A culture of transportation systems management and operations will be created over the next 10 years to focus increasingly on safety, security, customer service, and systems performance. The demands of both the external and internal environments are generating changes in the culture of both service providers and users.

Enabling Theme 2

ITS and the information management and communications capabilities that it brings will support a new level of cooperative operations among multiple agencies, across boundaries and travel modes. An increase in the level of investment in ITS by the public sector will improve the cost–benefit balance of the transportation network as a whole.

Enabling Theme 3

Traditional business–government partnerships need to be redefined to enhance private sector opportunities in the commercial marketplace. Government needs to help accelerate deployment by adopting and encouraging the adoption by others of appropriate ITS products and services.

Enabling Theme 4

While the new information opportunities that ITS creates are clearly valuable — in many cases essential, the sheer volume of information also creates potential problems, e.g., overload, distraction, and confusion. ITS designers must consider what the vehicle operator is capable of doing while operating a vehicle safely. User-centered design is a fundamental concept within human factors engineering and is a proven method of promoting effective, successful, and safe design.

The Stakeholders

More than a dozen major stakeholders are identified and called on to contribute to the realization of this plan. Most of these stakeholders fall into one of three macrolevel groups: the public sector, the private sector, and universities.

65.9 Case Study: Incident Management

Although congestion is recognized as a problem for commuters and motor carriers alike, information on the scope and cost of congestion is limited. A 1984 staff study by the FHWA found that freeway congestion in the nation's 37 largest metropolitan areas was responsible for 2 billion vehicle hours of delay at a cost of $16 billion [10,11]. By 2005, those figures could rise to as high as 8 billion vehicle hours and $88 billion annually. Most of the cost of congestion is borne by large cities. A dozen large urban areas account for more than 80% of freeway congestion cost. New York, Los Angeles, San Francisco, and Houston have the highest congestion costs, about $2 billion each in current dollars; Detroit, Chicago, Boston, Dallas, and Seattle, about $1 billion each; and Atlanta, Washington, D.C., and Minneapolis, about $500 million each. The patterns of past growth and the trends for the immediate future all point toward the conclusion that congestion will continue to be a significant metropolitan and national issue. Without attention, congestion will sap the productivity and competitiveness of our economy, contribute to air pollution, and degrade the quality of life in our metropolitan areas [10].

The term *recurring problem* is used to describe congestion when it routinely occurs at certain locations and during specific time periods. The term *nonrecurring problem* is used to describe congestion when it is due to random events such as accidents or, more generally, incidents [18].

Recurring Congestion

The most common cause of recurring congestion is excessive demand, the basic overloading of a facility that results in traffic stream turbulence. For instance, under ideal conditions, the capacity of a freeway is approximately 2000 to 2200 passenger cars per lane per hour. When the travel demand exceeds this number, an operational bottleneck will develop. An example is congestion associated with nonmetered freeway ramp access. If the combined volume of a freeway entrance ramp and the main freeway lanes creates a demand that exceeds the capacity of a section of freeway downstream from the ramp entrance, congestion will develop on the main lanes of the freeway, which will result in queuing upstream of the bottleneck. The time and location of this type of congestion can be predicted [18].

Another cause of recurring congestion is the reduced capacity created by a geometric deficiency, such as a lane drop, difficult weaving section, or narrow cross section. The capacity of these isolated sections, called geometric bottlenecks, is lower than that of adjacent sections along the highway. When the demand upstream of the bottleneck exceeds the capacity of the bottleneck, congestion develops and queuing occurs on the upstream lanes. As above, the resulting congestion can also be predicted [18].

Nonrecurring Congestion: Incidents

Delays and hazards caused by random events constitute another serious highway congestion problem. Referred to as temporary hazards or incidents, they can vary substantially in character. Included in this category is any unusual event that causes congestion and delay [18]. According to FHWA estimates, incidents account for 60% of the vehicle hours lost to congestion. Of the incidents that are recorded by police and highway departments, the vast majority, 80%, are vehicle disablements — cars and trucks that have run out of gas, have a flat tire, or have been abandoned by their drivers. Of these, 80% wind up on the shoulder of the highway for an average of 15 to 30 minutes. During off-peak periods when traffic volumes are low, these disabled vehicles have little or no impact on traffic flow. However, when traffic volumes are high, the presence of a stalled car or a driver changing a flat tire in the breakdown lane can slow traffic in the adjacent traffic lane, causing 100 to 200 vehicle hours of delay to other motorists [10].

An incident that blocks one lane of three on a freeway reduces capacity in that sense of travel by 50% and even has a substantial impact on the opposing sense of travel because of rubbernecking [12]. If traffic flow approaching the incident is high (near capacity), the resulting backup can grow at a rate of about 8.5 miles per hour — that is, after 1 hour, the backup will be 8.5 miles long [12,13]. Traffic also backs up on ramps and adjacent surface streets, affecting traffic that does not even intend to use the freeway.

Observations in Los Angeles indicate that in off-peak travel periods, each minute of incident duration results in 4 or 5 minutes of additional delay. In peak periods, the ratio is much greater [12,14].

Accidents account for only 10% of reported incidents. Most are the result of minor collisions, such as sideswipes and slow-speed rear-end collisions [10]. Forty percent of accidents block one or two lanes of traffic. These often involve injuries or spills. Each such incident typically lasts 45 to 90 minutes, causing 1200 to 2500 vehicle hours of delay [10,15]. It is estimated that major accidents make up 5 to 15% of all accidents and cause 2500 to 5000 vehicle hours of delay per incident [10,16]. Very few of these major incidents, typically those involving hazardous materials, last 10 to 12 hours and cause 30,000 to 40,000 vehicle hours of delay. These incidents are rare, but their impacts can be catastrophic and trigger gridlock [10]. To be sure, these statistics are location specific and may differ across areas in the United States.

Incident Management

Incident congestion can be minimized by detecting and clearing incidents as quickly as possible and diverting traffic before vehicles are caught up in the incident queue. Most major incidents are detected within 5 to 15 minutes; however, minor incidents may go unreported for 30 minutes or more [10]. Traffic information for incident detection is typically collected from loop detectors and includes occupancy and volume averaged at 20- to 60-second intervals, usually across all lanes. Detector spacing along the freeway is a half-mile on the average. Certain systems in the United States and Canada (e.g., California I-880 and Ontario's Queen Elizabeth Way) also use paired detectors to collect speed data [20].

During an incident the queue continues to build until the incident is cleared and traffic flow is restored. The vehicle hours of delay that accrue to motorists are represented in the exhibit by the area that lies between the normal flow rate and the lower incident flow rates. If the normal flow of traffic into the incident site is reduced by diverting traffic to alternate routes, the vehicle hours of delay are minimized (shaded area). If normal traffic flow is not diverted, additional vehicle hours of delay (hatched area) are accrued [10]. The time saved by an incident management program depends on how well the stages of an incident are managed.

Effective incident detection requires consideration of all major false alarm sources. In particular, traffic flow presents a number of inhomogeneities, hard to distinguish from those driven by incidents. Events producing traffic disturbances include bottlenecks, traffic pulses, compression waves, random traffic fluctuations, and incidents. Sensor failure, also treated as an event, is related only to the measurement component of detection systems. The major characteristics of each event are described below [20].

Incidents

Incidents are unexpected events that block part of the roadway and reduce capacity. Incidents create two traffic regimes, congested flow upstream (high occupancies) and uncongested downstream (low occupancies). Two shock waves are generated and propagate upstream and downstream, each accompanying its respective regime. The congested-region boundary propagates upstream at approximately 16 kilometers per hour (10 miles per hour), where the value depends on incident characteristics, freeway geometry, and traffic level. Downstream of the incident, the cleared region boundary propagates downstream at a speed that can reach 80 kilometers per hour (50 miles per hour) [50].

The evolution and propagation of each incident is governed by several factors, the most important of which are incident type, number of lanes closed, traffic conditions prior to incident, and incident location relative to entrance and exit ramps, lane drops or additions, sharp turns, grade, and sensor stations. Other, less important factors that are harder to model include pavement condition, traffic composition, and driver characteristics.

Incident patterns vary depending on the nature of the incident and prevailing traffic conditions [50]. The most distinctive pattern occurs when the reduced capacity from incident blockage falls below oncoming traffic volume so that a queue develops upstream. This pattern, which is clearest when traffic is flowing freely prior to the incident, is typical when one or more moving lanes are blocked following severe accidents. The second pattern type occurs when the prevailing traffic condition is freely moving but the impact of the incident is not severe. This may result, e.g., from lane blockage that still yields reduced capacity higher than the volume of incoming traffic. This situation may lead to missed detection, especially if the incident is not located near a detector. The third type characterizes incidents that do not create considerable flow discontinuity, as when a car stalls on the shoulder. These incidents usually do not create observable traffic shock waves and have limited or no noticeable impact on traffic operations. The fourth type of incident occurs in heavy traffic when a freeway segment is already congested. The incident generally leads to clearance downstream, but a distinguishable traffic pattern develops only after several minutes, except in a very severe blockage. This type of incident is often observed in secondary accidents at the congested region upstream of an incident in progress.

Bottlenecks

Bottlenecks are formed where the freeway cross section changes, e.g., in lane drops or additions. While incidents have only a temporary effect on occupancies, bottlenecks generally result in longer-lasting spatial density or occupancy discrepancies.

Traffic Pulses

Traffic pulses are created by platoons of cars moving downstream. Such disturbances may be caused by a large entrance ramp volume; for instance, a sporting event letting out. The observed pattern is an increase in occupancy in the upstream station followed by a similar increase in the downstream station. When ramp metering is present, traffic pulses are rarely observed.

Compression Waves

Compression waves occur in heavy, congested traffic, usually following a small disturbance, and are associated with severe slow-down, speed-up vehicle speed cycles. Waves are typically manifested by a sudden, large increase in occupancy that propagates through the traffic stream in a direction counter to the traffic flow. Compression waves result in significantly high station occupancies of the same magnitude as that in incident patterns.

Random Fluctuations

Random fluctuations are often observed in the traffic stream as short-duration peaks of traffic occupancy. These fluctuations, although usually not high in magnitude, may form an incident pattern or obscure real incident patterns.

Detection System Failures

Detection system failures may be observed in several forms, but a particular form often results in a specific pattern. This pattern is observed with isolated high-magnitude impulses in the 30-second volume and occupancy measurements, appearing simultaneously in several stations. These values are considered outliers or impulsive data noise [20].

Formulation of Incident Detection Problem

Incident detection can be viewed as part of a statistical decision framework in which traffic observations are used to select the true hypothesis from a pair, i.e., incident or no incident. Such a decision is associated with a level of risk and cost. The cost of a missed detection is expressed in terms of increased delays, and the cost of a false alarm is expressed in terms of incident management resources dispatched to the incident location. The objective of incident detection is to minimize the overall cost.

To formulate the incident detection problem in a simple incident versus no-incident environment, we observe the detector output that has a random character and seek to determine which of two possible causes, incident or normal traffic, produced it. The possible causes are assigned to a hypothesis, i.e., incident H_1 versus no-incident (normal traffic) H_0. Traffic information is collected in real time and processed through a detection test, in which a decision is made based on specific criteria. Traffic information, such as occupancy, represents the observation space. We can assume that the observation space corresponds to a set of N observations denoted by the observation vector **r.** Following a suitable decision rule, the total observation space Z is divided into two subspaces, Z_1 and Z_0. If observation **r** falls within Z_1, the decision is d_1; otherwise the decision is d_0.

To discuss suitable decision rules, we first observe that each time the detection test is performed four alternatives exist, depending on the true hypothesis H_i and the actual decision d_i, i = 0 or 1:

1. H_0 true; choose H_0 (correct "no incident" decision)
2. H_0 true; choose H_1 (false alarm)
3. H_1 true; choose H_1 (correct "incident" decision)
4. H_1 true; choose H_0 (missed incident)

The first and third alternatives correspond to correct choices; the second and fourth correspond to errors.

The Bayes' minimum error decision rule is based on the assumption that the two hypotheses are governed by probability assignments, known as a priori probabilities P_0 and P_1. These probabilities represent the observer's information about the sources (incident or no incident) before the experiment (testing) is conducted. Further, costs C_{00}, C_{10}, C_{11}, and C_{01} are assigned to the four alternatives. The first subscript indicates the chosen hypothesis and the second the true hypothesis. The costs associated with a wrong decision, C_{10}, C_{01}, are dominant. Each time the detection test is performed, the minimum error rule considers the risk (cost) and attempts to minimize the average risk. The risk function is written,

$$R = C_{00}P_0P\left(d_0/H_0\right) + C_{01}P_1P\left(d_0/H_1\right) + C_{10}P_0P\left(d_1/H_0\right) + C_{11}P_1P\left(d_1/H_1\right) \tag{65.1}$$

that is,

$$R = \sum\sum C_{ij}\, P_j\, P\left(d_i/H_j\right) \qquad i,\, j = 0,\, 1$$

where the conditional probabilities $P(d_i/H_j)$ result from integrating $p(\mathbf{r}/H_j)$, the conditional probability to observe the vector **r** over Z_i, the observation subspace in which the decision is d_i. In particular, the probability of detection is

$$P\left(d_1/H_1\right) = P_D = \int_{z_1} p\left(\mathbf{r}/H_1\right) dr$$

and the probability of false alarm is

$$P\left(d_1/H_0\right) = P_F = \int_{z_1} p\left(\mathbf{r}/H_0\right) dr$$

Minimizing the average risk yields the *likelihood ratio* test:

$$\Lambda\left(\mathbf{r}\right) = \frac{p\left(\mathbf{r}/H_1\right)}{p\left(\mathbf{r}/H_0\right)} \underset{H_0}{\overset{H_1}{\gtrless}} \frac{\left(c_{10} - c_{00}\right) P_0}{\left(c_{01} - c_{11}\right) P_1}$$

where the second part in the inequality represents the test threshold, and the conditional and a priori probabilities can be estimated through time observations of incident and incident-free data. However, obtaining an optimal threshold requires realistic assignment of costs to each alternative. This is further impeded by the fact that incidents (or false alarms) are not alike in frequency, impact, and consequences. Therefore, an optimal threshold cannot practically be established. Previous attempts to use the Bayes' decision rule employed a simplified risk function to overcome the cost assignment issue and reduce the calibration effort. For instance, Levin and Krause [51] obtained a suboptimal threshold by maximizing the expression

$$R = P\left(d_0/H_0\right) + P\left(d_1/H_1\right)$$

using the relative spatial occupancy difference between adjacent stations as the observation parameter.

An alternative procedure to Bayes' rule, applicable when assigning realistic costs or a priori probabilities is not feasible, is the Neyman–Pearson (NP) criterion. The NP criterion views the solution of the optimization of the risk function in Eq. (65.1) as a constrained maximization problem. This is necessitated by the fact that minimizing P_F and maximizing P_D are conflicting objectives. Therefore, one must be fixed while the other is optimized:

Constrain $P_F \leq \alpha$ and design a test to maximize P_D under this constraint.

Similarly to the minimum error criterion, the NP test results in a likelihood ratio test:

$$\Lambda(\mathbf{r}) \geq \lambda$$

where the threshold λ is a function of P_F only. Decreasing λ is equivalent to increasing Z_1, the region where the decision is d_1 (incident). Thus, both P_F and P_D increase as λ decreases. The Neyman–Pearson *lemma* [52] implies that the maximum P_D occurs at $P_F = \alpha$.

The lemma holds since P_D is a nondecreasing function of P_F. In practical terms, an NP procedure implies that after an incident test has been designed, it is applied to a data set initially employing a high (restrictive) threshold, which results in low P_F. The threshold is incrementally reduced until P_F increases to the upper tolerable limit α. The corresponding P_D represents the detection success of the test at false alarm α. An NP procedure seems more applicable to incident detection than a minimum error procedure for two reasons. First, the only requirement is the constraint on P_F, which can easily be assessed by traffic engineers to a tolerable limit. Second, an NP procedure does not require separate threshold calibration since no optimal threshold, in the Bayesian sense, is sought. Instead, thresholds result from the desirable P_F.

The decision process is facilitated by the likelihood ratio $\Lambda(\mathbf{r})$. In signal detection practice, $\Lambda(\mathbf{r})$ is replaced by a *sufficient statistic* $l(\mathbf{r})$, which is simpler than the $\Lambda(\mathbf{r})$ function of the data. The values of the sufficient statistic are then compared to appropriate thresholds to decide which hypothesis is true. In incident detection applications, however, the tests of an algorithm are designed empirically so that they only approximately can be considered as sufficient statistics.

Need for All Incident Management Stages to Perform

Classical incident management strategies at the incident management components of detection, verification, response, and traffic management are aimed at minimizing the negative effects of nonrecurrent congestion that are due to incidents. The basic idea is that fast clearance of the incident scene can help to alleviate the incident-related congestion. Early and reliable detection and verification of the incident, together with integrated motorway and nonmotorway traffic management strategies, are important contributions that improve the efficiency of the incident response, i.e., the actions taken once an incident has occurred. However, it would still be better if the incident had been avoided in the first place. A first requirement, then, is that one can recognize conditions in which an incident is more likely to occur. The component of incident probability estimation should be developed and added to the incident management suite for this purpose.

Automatic incident detection (AID) involves two major elements: a traffic detection system that provides the traffic information necessary for detection and an incident detection algorithm that interprets the information and ascertains the presence or absence of a capacity-reducing incident.

Most AID algorithms have been developed based on loop detector data. Detection has typically been based on models that determine the expected traffic state under normal traffic conditions and during incidents. Comparative (or pattern recognition) algorithms establish predetermined incident patterns in traffic measurements and attempt to identify these patterns by comparing detector output against preselected thresholds. One of these involves separating the flow-occupancy diagram into areas corresponding to different states of traffic conditions (e.g., congested and not congested) and detecting incidents after observing short-term changes of the traffic state. These algorithms operate on a detector output of 30- to 60-second occupancy and volume data.

Time series and statistical algorithms employ simple statistical indicators or time series models to describe normal traffic conditions and detect incidents when measurements deviate significantly from the model output. A third class includes algorithms that involve macroscopic traffic flow modeling to describe the evolution of traffic variables; the diversity of incident patterns requires development of a large number of pattern-specific models, and this has limited the potential of these algorithms for practical applications. Other methods include detection of stationary or slow-moving vehicles, filtering to reduce the undesired effects of traffic disturbances, application of fuzzy sets, transform analysis, and neural networks to take advantage of learning processes.

Recent work addressed the vehicle reidentification problem, lexicographic optimization, and derivation of section-related measures of traffic system performance using current inductive loops that provide vehicle waveforms. Another promising recent work performs real-time detection and characterization of motorway incidents using a three-step process, i.e., symptom identification of anomalous changes in traffic characteristics, signal processing for stochastic estimation of incident-related lane traffic characteristics, and pattern recognition.

In Europe, algorithms tested with data from loops are of the comparative type (e.g., HERMES I; German I, II, and IV; and Dutch MCSS), time series type (GERDIEN), or the type employing filtering (HERMES II). They use typical aggregate data (speed, volume, and occupancy) and aim to detect congestion and slow-moving or stopped vehicles. Other AID techniques extract traffic data from radar, such as the Millimetric Radar System (MMW) and German III. Using machine vision, AID systems serve as loop detector emulators (CCATS VIP and IRB), qualitative traffic state detectors (IMPACTS), or vehicle tracking detectors (TRISTAR and CCIDS).

Despite substantial research, algorithm implementation has been hampered by limited performance reliability, substantial implementation needs, and strong data requirements. Several problems require the attention of developers:

False alarm rate (FAR): The high number of false alarms has discouraged traffic engineers from integrating these algorithms in automated traffic operations. Algorithm alarms typically trigger the operator's attention; the operator verifies the validity of the alarm using closed-circuit TV cameras and decides on the appropriate incident response. In most cases, incident response is initiated only after an incident has been reported by the police or motorists.

Calibration: The need for algorithm calibration has not been extensively assessed, and lack of adequate calibration often leads to significantly deteriorated algorithm performance. Calibration by optimization of a set of different algorithms on the same field data set is the most reliable way for comparative evaluation across algorithms.

Evaluation: The major method adopted for comparatively evaluating the performance of AID algorithms is that of the operating characteristic curves. Performance tests have shown the following [53]:

United States

Time series algorithms performed worse than comparative ones.

DELOS, an algorithm based on filtering, produced 50% fewer false alarms than comparative algorithms, e.g., California type.

The time series algorithm by Persaud et al. produced a good detection rate but too many false alarms to be practical.

France

Comparative algorithms produced at least 30% fewer false alarms than single-variable time series algorithms (Standard Normal Deviate, Double Exponential, and ARIMA) at all detection levels.

DELOS performed better than the time series algorithm developed by Persaud et al.

IN-RESPONSE Project in Europe

DELOS and Algorithm 8 were evaluated against machine vision methods, and the results showed each to have its strengths under given conditions.

Canada

The time series algorithm by Persaud et al. produced fewer false alarms than the California algorithm and was adopted as its replacement.

Transferability: Some understanding of algorithm transferability potential has been achieved, mainly in the IN-RESPONSE, HERMES, MARGOT-LLAMD, and EUROCOR projects and in a comparative evaluation in Minnesota and California (analysis of 213 incidents over 1660 hours, 24 hours a day) [54].

Traffic management objectives: While most U.S. efforts seek to remove the incident and achieve smooth traffic flow, work in Europe focuses on warning drivers of congestion even if no incident has occurred and on assisting stopped vehicles. Work in rural areas has focused on achieving AID with sparse instrumentation. The latter two objectives can often best be addressed by AID systems that are based on machine vision. Such systems have achieved performance equivalent to that of loop detectors. However, the additional advantage of the new systems is that they can detect incidents that do not influence traffic substantially or that cannot be detected by loop-based systems but are still a risk to the motorist.

Addressing the need for determining improved performance of incident detection methods under varying conditions, a recent project, PRIME, tested incident detection algorithms that have not been extensively tested in Europe, and more advanced sensing hardware. The project addressed all incident management components, i.e., estimation of incident probability, incident detection, incident verification, and integrated incident response strategies. Recent results from the project indicate that the **incident detection** component has satisfied the specifications in terms of detection rate and false alarm rate. For instance, application of the modified Persaud algorithm in Barcelona resulted in the performance envelope shown in Fig. 65.5 [55].

The real-time **estimation of incident probability** is sparsely documented.

From IN-RESPONSE [56], it was concluded that the incident probability estimation model was a promising way of linking real-time 1-minute traffic and weather data to static data on road geometry for estimating incident probability. The technique could not be properly evaluated because of the shortage of incident data and the inaccuracy of the time stamps.

The same lack of incident data was reported in Reference 57. The authors presented several empirical methods for analyzing incident data. A key issue raised was whether an accident was responsible for the measured variability in traffic conditions or whether these conditions were caused by the accident.

The problem of data availability was not reported in Reference 58, which used a model similar to that in IN-RESPONSE (binary logit) to establish relationships between incident likelihood and explanatory variables such as weather and traffic conditions.

A method of overcoming this shortage of incident data is to simulate incident situations [59]. The cellular automaton–based microscopic simulation model TRANSIMS was used to estimate the probability

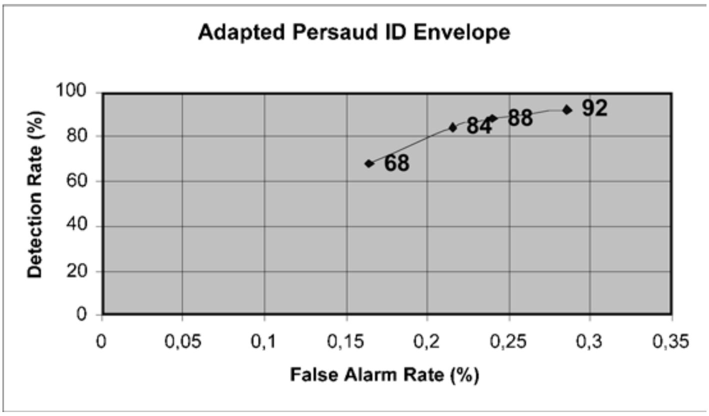


FIGURE 65.5 Performance envelope. (Used with permission from J. Barcelo and L. Montero.)

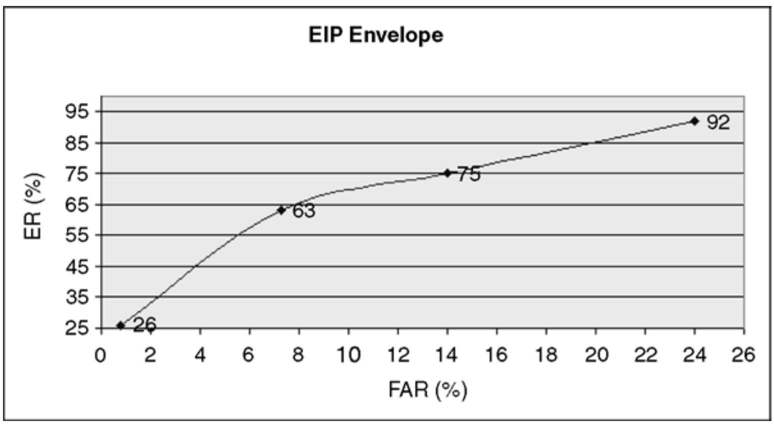


FIGURE 65.6 Performance envelope. (Used with permission from J. Barcelo and L. Montero.)

of accidents. The model used a relationship between the probability of an incident and a safety criterion (braking power).

PRIME developed EIP hierarchical logit, logit, and fuzzy models with online data and simulation. The performance was good in terms of estimation rate but had several false alarms; see the performance envelope shown in Fig. 65.6 with data from Barcelona.

Incident verification (IV) aims to accumulate evidence and information about possible detected incidents and use this additional information to drop false alarms, merge repeated alarms, and provide complete incident reports in case of real incidents.

Most countries with an operational traffic management system are using one or more incident verification methods, primarily CCTV and patrol vehicles. Realizing the potential of using cellular telephones as an incident management tool, many highway agencies have formed partnerships with cellular telephone carriers to implement programs that encourage drivers to report randomly occurring motorway incidents.

However, information obtained from cellular phones varies in the detail and quality, and the incident may be reported after considerable time has elapsed. Therefore, the feasibility of motorway surveillance systems utilizing cellular phones needs to be carefully evaluated. A survey of 42 traffic management centers in the United States found that 75% use cellular detection. However, in most states, such as Texas, video cameras are deployed for verification. Weaknesses of cellular phones include a very low rate of

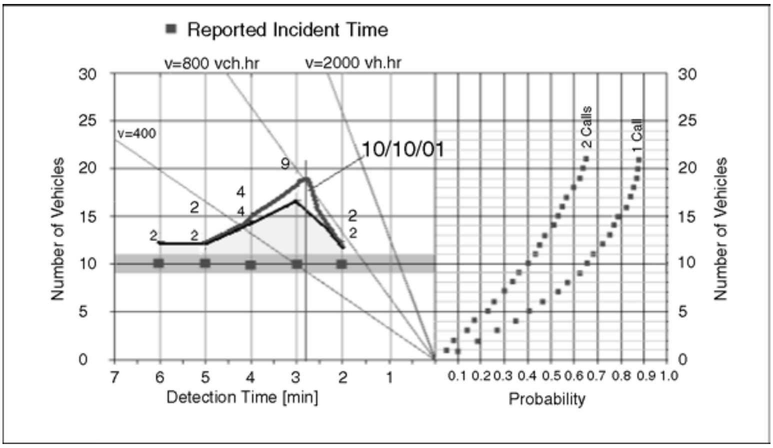


FIGURE 65.7 Effect of parameters on performance. (Used with permission from B. Dendrou.)

detecting small incidents, the highest rate of false alarms, and limited information on the incident severity. Also, cellular phone messages need further verification and cannot tell when the incident is cleared. Incidents reported by cellular phones show greater incident duration by 14 minutes on the average than similar incidents reported by the CHP/MSP. This extra delay is due to the incident verification process by dispatching an officer.

Cellular phone false alarms fall into two categories: (1) reporting incorrect or incomplete information regarding the location of the incident and its severity and (2) erroneous calls, including fake or prank calls. On the other hand, wireless phone users can report incidents that traditional methods cannot capture, such as debris, flooding, or wandering animals.

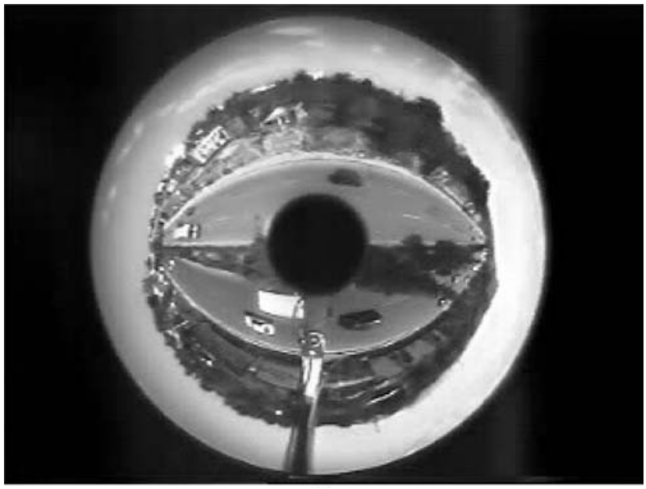
Incident management requirements for incident verification within advanced transport telematics (ATT) systems cannot rely solely on cellular phones. Cellular phone reports may contribute significantly to the incident detection in combination with other sources and may be used in the verification of incidents, including those detected by other methods. This would require proper fusion of cellular phone data with information from other sources and use of appropriate technologies, such as video surveillance.

When all sites use the same automated and reliable procedure, consistent information about the incidents will be collected. Information that could be retrieved to verify an incident in this way can include one or more incident attributes, e.g.:

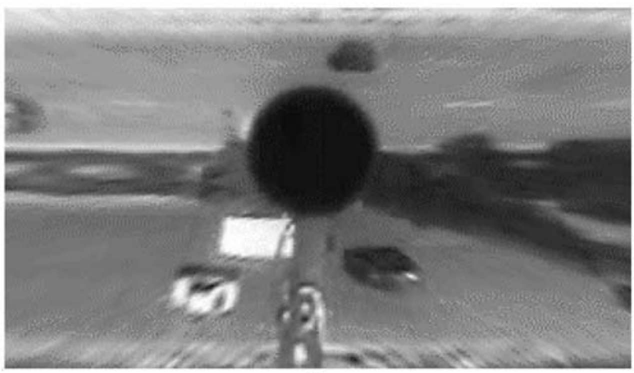
- Location (road number, travel direction, kilometer point, and lane)
- Type and severity (injuries, fire, trapped injuries, or hazardous goods)
- Identity of source
- Type of assistance needed (mechanical, police, or emergency)
- Certainty

Results with data from Athens, Greece indicate the effect of parameters on performance, i.e., the effect of the number of calls required, mobile phone penetration, traffic volume, etc.; see Fig. 65.7 [55].

Additional performance improvements in PRIME were attained with the development of specialized hardware and software, such as panoramic camera and accompanying algorithms that transform the original image acquired by a panoramic camera (Fig. 65.8a) to a bird-eye view that can be further processed (Fig. 65.8b) and, through a homography-based transformation, transform the original image of a machine vision camera (Fig. 65.8c) to top-down view (Fig. 65.8d) for easier calculations and error reduction [55].



(a)



(b)

FIGURE 65.8 (a) Original image acquired by panoramic camera. (b) Bird-eye transformation of (a). (Courtesy of Computer Vision and Robotics Lab, Institute of Computer Science, FORTH, Heraklion, Crete, Greece.)

(c)

(d)

FIGURE 65.8 (c) Original image of machine vision camera. (d) Homography-based transformation of (c) to top-down view.

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Appendix

TABLE 65.1 Incident Management Assessment Summary

Technology	Deployment Level	Limiting Factors	Comments
Service patrols	Widespread deployment	Cost, staffing	Successful
Common communication frequencies	Limited deployment[a]	Cost, institutional issues	Successful
Automated incident detection algorithms	Medium deployment[a]	Technical performance	Mixed
Cellular communication for incident detection	Widespread deployment	Availability, institutional issues	Jury is still out
Motorist call boxes	Limited deployment[a]	Being replaced by cell phone use	Successful
CCTV (ground, airborne, high magnification)	Widespread deployment	Cost	Successful
Cellular geolocation (old generation)	Operational testing[a]	Accuracy	Unsuccessful
Cellular geolocation (emerging generation)	Operational testing[a]	Availability, institutional issues	Jury is still out
Regional incident management programs	Limited deployment[a]	Institutional isues	Holds promise

[a] Quantitative deployment tracking data not available. Deployment level determined by expert judgment.

Source: Federal Highway Administration, What Have We Learned about Intelligent Transportation Systems? U.S. Department of Transportation, Washington, D.C., 2000.

TABLE 65.2 Freeway Management Assessment Summary

Technology/System	Deployment Level	Limiting Factors	Comments
Transportation management centers (may incorporate multiple technologies)[a]	Widespread deployment[b]	Implementation cost, staffing	Successful
Portable transportation management centers (may incorporate multiple technologies)	Limited deployment[b]	Implementation cost, staffing	Successful
Road closure and restriction systems (may incorporate multiple technologies)	Limited deployment[b]	Institutional issues	Successful
Vehicle detection systems (may incorporate multiple technologies)	Widespread deployment	Cost, maintenance	Mixed — depends on technology
Vehicles as probes (may incorporate multiple technologies)	Limited deployment	Cost, integration	Jury is still out
Ramp metering (includes multiple technologies)	Medium deployment	Politics, user appearance	Successful
Dynamic message signs (includes multiple technologies)	Widespread deployment	Cost, changing technology	Mixed — due to operations quality
Highway advisory radio (includes multiple technologies)	Medium deployment	Staffing	Mixed — due to operations quality
Dynamic lane control	Medium deployment	Not in MUTCD for main lanes[c]	Successful — especially on bridges and in tunnels
Dynamic speed control/variable speed limit	Technical testing[b]	Not in MUTCD; may require local legislation to be enforceable	Holds promise
Downhill speed warning and rollover warning systems	Limited deployment[b]	Cost	Successful

[a] A transportation management center may control several of the systems listed in the table and will possibly utilize additional technologies, such as video display systems, local area networks, flow monitoring algorithms, geographic information systems, graphic user interfaces, and database management systems.

[b] Quantitative deployment tracking data not available. Deployment level determined by expert judgment.

[c] Main lanes are freeway lanes that are not tunnels or bridges.

Source: Federal Highway Administration, What Have We Learned about Intelligent Transportation Systems? U.S. Department of Transportation, Washington, D.C., 2000.

TABLE 65.3 Emergency Management Assessment Summary

Technology	Deployment Level	Limiting Factors	Comments
GPS/differential GPS on emergency management fleets	Widespread deployment	Cost	Successful
Mayday systems	Widespread deployment[a]	Cost, vehicle choice	Successful
Mayday processing centers/customer service centers	Widespread deployment[a]	Cost	Successful
Public safety answering points	Widespread deployment[a]	Cost, staffing	Successful
CDPD communication	Limited deployment[a]	Availability	Jury is still out
Onboard display	Widespread deployment	Cost, user acceptance	Successful
Preemption infrared signal system	Widespread deployment	Institutional issues, lack of standards	Successful
Computer-aided dispatch	Widespread deployment	Cost, support staffing	Successful
Automatic vehicle location	Widespread deployment	Cost	Successful
Networked systems among agencies	Limited deployment[a]	Institutional issues, integration cost	Holds promise

[a] Quantitative deployment tracking data not available. Deployment level determined by expert judgment.

Source: Federal Highway Administration, What Have We Learned about Intelligent Transportation Systems? U.S. Department of Transportation, Washington, D.C., 2000.

TABLE 65.4 Electronic Toll Collection Assessment Summary

Technology	Deployment Level	Limiting Factors	Comments
Dedicated short-range communication	Widespread deployment	Need for standard	Successful
Smart cards	Limited deployment	Commercial and user acceptance; need for standard	Successful
Transponders	Widespread deployment	Privacy	Successful
Antennas	Widespread deployment	Technical performance	Successful
License plate recognition	Limited deployment[a]	Technical performance	Jury is still out

[a] Quantitative deployment tracking data not available. Deployment level determined by expert judgment.

Source: Federal Highway Administration, What Have We Learned about Intelligent Transportation Systems? U.S. Department of Transportation, Washington, D.C., 2000.

TABLE 65.5 Arterial Management Asssessment Summary

Technology	Deployment Level	Limiting Factors	Comments
Adaptive control strategies	Limited deployment	Cost, technology, perceived lack of benefits	Jury is still out — has shown benefits in some cases; cost still a prohibitive factor; some doubt among practitioners on its effectiveness
Arterial information for ATIS	Moderate deployment	Limited deployment of appropriate surveillance; difficulty in accurately describing arterial congestion	Holds promise — new surveillance technology likely to increase the quality and quantity of arterial information
Automated red light–running enforcement	Moderate deployment[a]	Controversial; some concerns about privacy, legality	Successful — but must be deployed with sensitivity and education
Automated speed enforcement on arterial streets	Limited deployment[a]	Controversial; some concerns about privacy, legality	Jury is still out — public acceptance lacking; very controversial
Integration of time-of-day and fixed-time signal control across jurisdictions	Widespread deployment	Institutional issues still exist in many areas	Successful — encouraged by spread of closed-loop signal systems and improved communications
Integration of real-time or adaptive control strategies across jurisdictions (including special events)	Limited deployment	Limited deployment of adaptive control strategies; numerous institutional barriers	Holds promise — technology is becoming more available; institutional barriers falling
Integration with freeway (integrated management)	Limited deployment	Institutional issues exist; lack of standards between systems preventing integration	Holds promise — benefits have been realized from integrated freeway arterial corridors
Integration with emergency (signal preemption)	Widespread deployment	None	Successful
Integration with transit (signal priority)	See Chapter 5, "What Have We Learned about Advanced Public Transportation Systems?"	See Chapter 5, "What Have We Learned about Advanced Public Transportation Systems?"	See Chapter 5, "What Have We Learned about Advanced Public Transportation Systems?"

[a] Quantitative deployment tracking data not available. Deployment level determined by expert judgment.

Source: Federal Highway Administration, What Have We Learned about Intelligent Transportation Systems? U.S. Department of Transportation, Washington, D.C., 2000.

TABLE 65.6 ATIS Assessment Summary

ATIS Service	Deployment Level	Limiting Factors	Comments
Real-time traffic information on the Internet	Widespread deployment	While deployment is widespread, customer satisfaction with the services seems related to local traffic conditions and website information quality	Mixed — the characteristics of the websites vary, depending on the availability and quality of the user interface and underlying traffic data
Real-time transit status information on the Internet	Limited deployment	Transit authorities have limited funds for ATIS investments and little data that establish a relationship between ridership and ATIS	Holds promise — where the service is available, reports suggest that there is high customer satisfaction with the service
Static transit system information on the Internet	Widespread deployment	N/A	Successful
Real-time traffic information on cable television	Limited deployment	Limited by information quality and production costs, although one service provider has developed a way to automate production	Successful — as evaluated in a highly congested metropolitan area where consumers value the easy, low-tech access to traffic information
Real-time transit status information at terminals and major bus stops	Limited deployment	Cost	Successful — where evaluated in greater Seattle
Dynamic message signs	Widespread deployment	Positive driver response is a function of sign placement, content, and accuracy	Successful — drivers really appreciate accurate en route information
In-vehicle navigation systems (no traffic information)	Limited deployment[a]	Purchase cost	Holds promise — as prices fall, more drivers will purchase the systems
In-vehicle dynamic route guidance (navigation with real-time traffic information)	No commercial deployment; the San Antonio MMDI installed prototype systems in public agency vehicles[a]	Irregular coverage and data quality, combined with conflicting industry geocode standards, have kept this product from the market	Holds promise — manufacturers are poised to provide this service once issues are resolved
Fee-based traffic and transit information services on palm-type computers	Unknown deployment	Service providers make this service available through their websites; actual subscription levels are unknown	Jury is still out — requires larger numbers of subscribers becoming acclimated to mobile information services

Note: N/A = not applicable.

[a] Quantitative deployment tracking data not available. Deployment level determined by expert judgment.

Source: Federal Highway Administration, What Have We Learned about Intelligent Transportation Systems? U.S. Department of Transportation, Washington, D.C., 2000.

TABLE 65.7 APTS Assessment Summary

Technology	Deployment Level	Limiting Factors	Comments
Automatic vehicle location	Moderate deployment	Cost, fleet size, service type, staff technological competence	Successful — use continues to grow; new systems principally use GPS technology, but usually augmented by dead reckoning
Operations software	Widespread deployment	N/A	Successful
Fully automated dispatching for demand response	Research and development[a]	Still in research and development stage	Jury is still out
Mobile data terminals	Moderate deployment[a]	Most frequently deployed with automatic vehicle location systems	Successful — reduces radio frequency requirements
Silent alarm/covert microphone	Moderate deployment[a]	Most frequently deployed with automatic vehicle location systems	Successful — improves security of transit operations
Surveillance cameras	Limited deployment[a]	Cost	Holds promise — enhances onboard security; deters vandalism
Automated passenger counters	Limited deployment	Cost	Holds promise — provides better data for operations, scheduling, planning, and recruiting at lower cost
Pretrip passenger information	Widespread deployment	N/A	Successful — improves customer satisfaction
En route and in-vehicle passenger information	Limited deployment	Cost, lack of evidence of ridership increases	Jury is still out
Vehicle diagnostics	Limited deployment	Cost, lack of data on benefits	Jury is still out
Traffic signal priority	Limited deployment	Institutional issues, concerns about impacts on traffic flows	Holds promise — reduces transit trip times; may reduce required fleet size
Electronic fare payment	Limited deployment	Cost	Holds promise — increases customer convenience

Note: N/A = not applicable.

[a] Quantitative deployment tracking data not available. Deployment level determined by expert judgment.

Source: Federal Highway Administration, What Have We Learned about Intelligent Transportation Systems? U.S. Department of Transportation, Washington, D.C., 2000.

TABLE 65.8 CVISN Assessment Summary

Technology	Deployment Level	Limiting Factors	Comments
		Safety Information Exchange	
Laptop computers with Aspen or equivalent	Widespread deployment	N/A	Successful
Wireless connections to SAFER at roadside	Moderate deployment	Technical challenges with communications among systems	Holds promise — for identifying frequent violators of safety laws
CVIEW or equivalent	Limited deployment	Connections to legacy state system	Jury is still out — being tested in three or four states
		Electronic Screening	
One or more sites equipped with DSRC	Widespread deployment (number of states); limited deployment (number of carriers)	Interoperability	Holds promise — deployment trend is positive
		Electronic Credentialing	
End-to-end IRP and IFTA processing	Limited deployment	Challenges and costs of connecting legacy systems	Holds promise — potential for significant cost savings to states and carriers
Connection to IRP and IFTA clearinghouses	Limited deployment	Institutional issues	Jury is still out — cost savings can be realized only with widespread deployment

TABLE 65.9 Crosscutting Technical Issues Assessment Summary

Technology	Deployment Level	Limiting Factors	Comments
	Sensor and Surveillance Technologies		
Cell phones for incident reporting	Widespread deployment[a,b]	N/A	Successful
Cell phones for emergency notification	Limited deployment[a,b]	Relatively new; mostly sold in new vehicles; takes long time to reach 30% of vehicle fleet	Successful — number of equipped vehicles growing rapidly
GPS for position, determination, automatic vehicle location	Moderate deployment in fleets (transit, trucking, emergency vehicles) [c]	N/A	Successful — use continuing to grow[c]
Video surveillance	Widespread deployment	N/A	Successful
DSRC (toll tags) for travel time data	Limited deployment	Mostly used only in areas with electronic toll collection; requires power and communications to readers	Successful — holds promise
Direct link between Mayday systems and public safety answering points	Limited deployment[b]	Still in research and test phase; significant institutional policy and technical issues	Jury is still out — no known deployments
Cellular geolocation for traffic probes	Limited deployment	New technologies just beginning field trials	Jury is still out — older technology unsuccessful
	Communications Technologies		
Loop detectors	Widespread deployment	N/A	Successful
Alternatives to loop detectors	Widespread deployment	Initial cost, familiariy	Holds promise — video widespread; others limited; many cities use only for a few locations
Real-time, in-vehicle traffic information	Limited deployment[a,b]	Cost, commercial viability	Jury is still out
LIDAR for measuring automotive emissions	Limited deployment[b]	Minnesota test was unsuccessful; technology didn't work well enough	Unsuccessful — no known deployment
Internet for traveler information	Widespread deployment	N/A	Successful — free services Jury is still out — on commerical viability
High-speed Internet	Limited deployment[b]	Slow rollout; availability limited	Holds promise
Fully automated Internet-based exchange	Limited deployment[b]	New technology	Holds promise
DSRC	Widespread deployment	N/A	Successful — current use mostly limited to electronic toll collection
DSRC at 5.9 GHz	Limited deployment[b]	Frequency just recently approved for use; standards in development	Jury is still out — no known deployment in the U.S., but used in other countries at 5.8 GHz
Fiber optics for wire line communications	Widespread deployment	N/A	Successful
Digital subscriber line	Limited deployment	New technology; first applied to ITS in 1999	Holds promise — several deployments; many more locations considering
220-MHz radio channels for ITS	Limited deployment	ITS is too small a market to support unique communications systems	Unsuccessful — only known use during Atlanta test during the 1996 Olympic Games

TABLE 65.9 (continued) Crosscutting Technical Issues Assessment Summary

Technology	Deployment Level	Limiting Factors	Comments
High-speed FM subcarrier for ITS	Limited deployment[a,b]	Low demand to date for in-vehicle real-time data	Jury is still out — multiple conflicting "standards" and proprietary approaches; competition from other wireless technologies
CDPD for traveler information	Limited deployment[a,b]	Lack of real-time information to send; limited use of CDPD by consumers	Unsuccessful — CDPD will soon be overtaken by other wireless data technologies
Wireless Internet	Limited deployment[a,b]	New technology	Jury is still out — on ITS uses; general use predicted to grow rapidly
Local area wireless	Limited deployment	New technology	Jury is still out
Low-power FM	Limited deployment[b]	Just legalized by FCC; first licenses not yet granted	Jury is still out — brand new; no deployments yet
High-speed fixed wireless	Limited deployment[b]	New technology	Jury is still out
	Analysis Tools		
Models incorporating operations into transportation planning	Limited deployment[b]	Emerging technology; cost and institutional issues may become factors for some approaches	Jury is still out — IDAS available; PRUEVIIN methodology demostrated; TRANSIMS in development

Note: N/A = not applicable; FCC = Federal Communications Commission.

[a] Quantitative deployment tracking data are not available. Deployment level was determined by expert judgment.

[b] For in-vehicle consumer systems, deployment levels are based on the percent of users or vehicle fleet, not number of cities available. For example, real-time in-vehicle traffic is available in more than two dozen cities, but the percentage of drivers subscribing to it is small.

[c] For AVL using GPS in transit, the moderate-level assessment is based on the percent of transit agencies using the technology according to a 1998 survey of 525 transit agencies conducted by the John A. Volpe National Transportation Systems Center. This measure was used for consistency with the transit section of this report. If the 78 major metropolitan areas are used as a measure, then the deployment level is "widespread," as 24 of 78 cities use GPS-based AVL.

Source: Federal Highway Administration, What Have We Learned about Intelligent Transportation Systems? U.S. Department of Transportation, Washington, D.C., 2000.

TABLE 65.10 Definitions of the Metropolitan Integration Links

Definitions of the metropolitan integration links represent both inter- and intracomponent sharing of information. Each of the links has been assigned a number and an origin or destination path from one component to another. The definitions used are from the most recent version of the draft report titled "Tracking the Deployment of the Integrated Metropolitan Intelligent Transportation Systems Infrastructure in the USA: FY 1999 Results," prepared by the Oak Ridge National Laboratory and Science Applications International Corporation for the U.S. Department of Transportation's ITS Joint Program Office, dated March 2000.

Link 1: Arterial management to regional multimodal traveler information: Arterial travel time, speed, and condition information is displayed by regional multimodal traveler information media.

Link 2: Arterial management to freeway management: Freeway management center monitors arterial travel times, speeds, and conditions using data provided from arterial management to adjust ramp meter timing, lane control, or HAR in response to changes in real-time conditions on a parallel arterial.

Link 3: Arterial management to transit management: Transit management adjusts transit routes and schedules in response to arterial travel time, speed, and condition information collected as part of arterial management.

Link 4: Arterial management to incident management: Incident management monitors real-time arterial travel times, speeds, and conditions using data provided from arterial management to detect arterial incidents and manage incident response activities.

Link 5: Incident management to arterial management: Arterial management monitors incident severity, location, and type information collected by incident management to adjust traffic signal timing or provide information to travelers in response to incident management activities.

Link 6: Incident management to regional multimodal traveler information: Incident location, severity, and type information is displayed by regional multimodal traveler information media.

Link 7: Incident management to emergency management: Incident severity, location, and type data collected as part of incident management are used to notify emergency management for incident response.

Link 8: Incident management to freeway management: Incident severity, location, and type data collected by incident management are monitored by freeway management for the purpose of adjusting ramp meter timing, lane control, or HAR messages in response to freeway or arterial incidents.

Link 9: Incident management to transit management: Transit management adjusts transit routes and schedules in response to incident severity, location, and type data collected as part of incident management.

Link 10: Freeway management to regional multimodal traveler information: Freeway travel time, speed, and condition information is displayed by regional multimodal traveler information.

Link 11: Freeway management to arterial management: Freeway travel time, speed, and condition data collected by freeway management are used by arterial management to adjust arterial traffic signal timing or arterial VMS messages in response to changing freeway conditions.

Link 12: Freeway management to transit management: Transit management adjusts transit routes and schedules in response to freeway travel time, speed, and condition information collected as part of freeway management.

Link 13: Freeway management to incident management: Incident management monitors freeway travel time, speed, and condition data collected by freeway management to detect incidents or manage incident response.

Link 14a: Transit management to regional multimodal traveler information: Transit routes, schedules, and fare information is displayed on regional multimodal traveler information media.

Link 14b: Transit management to regional multimodal traveler information: Transit schedule adherence information is displayed on regional multimodal traveler information media.

Link 15a: Transit management to freeway management: Freeway ramp meters are adjusted in response to receipt of transit vehicle priority signal.

Link 15b: Transit management to freeway management: Transit vehicles equipped as probes are monitored by freeway management to determine freeway travel speeds or travel times.

Link 16a: Transit management to arterial management: Traffic signals are adjusted in response to receipt of transit vehicle priority signal.

Link 16b: Transit management to arterial management: Transit vehicles equipped as probes are monitored by arterial management to determine arterial speeds or travel times.

Link 17: Electronic toll collection to freeway management: Vehicles equipped with electronic toll collection tags are used as probes and monitored by freeway management to determine freeway travel speeds or travel times.

Link 18: Electronic toll collection to arterial management: Vehicles equipped with electronic toll collection tags are used as probes and monitored by arterial management to determine arterial travel speeds or travel times.

Link 19: Electronic toll collection to electronic fare payment: Transit operators accept electronic toll collection–issued tags to pay for transit fares.

Link 20: Electronic fare payment to transit management: Ridership details collected as part of electronic fare payment are used in transit service planning by transit management.

Link 21a: Emergency management to incident management: Incident management is notified of incident location, severity, and type by emergency management to identify incidents on freeways or arterials.

TABLE 65.10 (continued) Definitions of the Metropolitan Integration Links

Link 21b: Emergency management to incident management: Incident management is notified of incident clearance activities by emergency management to manage incident response on freeways or arterials.
Link 22: Emergency management to arterial management: Emergency management vehicles are equipped with traffic signal priority capability.
Link 23: Highway–rail intersection to incident management: Incident management is notified of crossing blockages by highway–rail intersection to manage incident response.
Link 24: Highway–rail intersection to arterial management: Highway–rail intersection and arterial management are interconnected for the purpose of adjusting traffic signal timing in response to train crossing.
Link 25: Incident management intracomponent: Agencies participating in formal working agreements or incident management plans coordinate incident detection, verification, and response.
Link 26: Arterial management intracomponent: Agencies operating traffic signals along common corridors share information and possible control of traffic signals to maintain progression on arterial routes.
Link 27: Electronic fare payment intracomponent: Operators of different public transit services share common electronic fare payment media.
Link 28: Electronic toll collection intracomponent: Electronic toll collection agencies share a common toll tag for the purpose of facilitating "seamless" toll transactions.
Link 29: Transit management to incident management: Transit agencies notify incident management agencies of incident locations, severity, and type.
Link 30: Freeway management intracomponent: Agencies operating freeways within the same region share freeway travel time, speed, and condition data.

Source: Mitretek Systems, ITS Benefits: Data Needs Update 2000, prepared in connection with ITS Benefits Data Needs Workshop, August 2000.